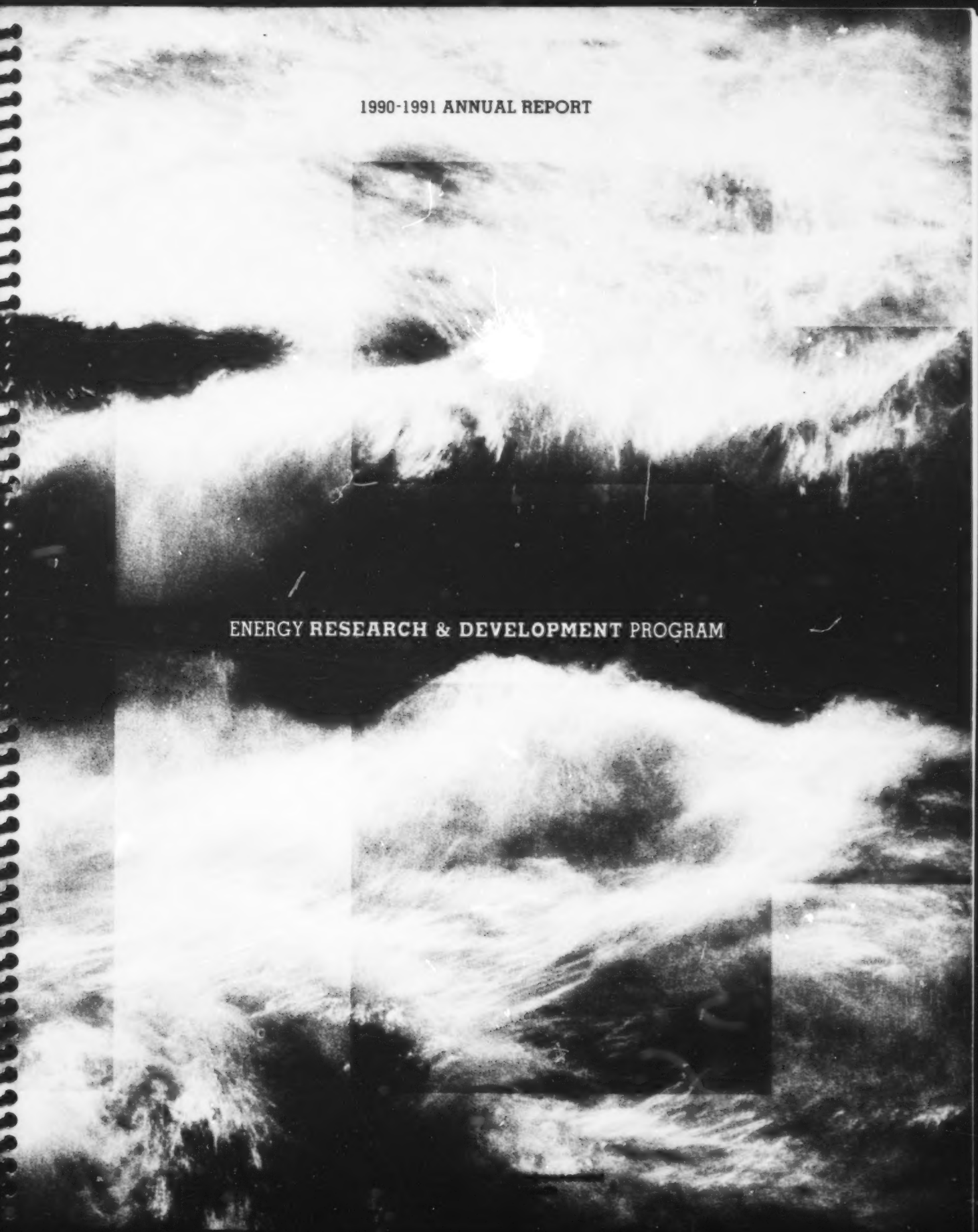


1990-1991 ANNUAL REPORT

ENERGY RESEARCH & DEVELOPMENT PROGRAM

1990-1991 ANNUAL REPORT

ENERGY RESEARCH & DEVELOPMENT PROGRAM

OFFICE OF THE SCIENCE ADVISOR
ENVIRONMENT CANADA
June 1992

93-02612/

▸ For further information concerning this publication and the program, please direct your enquiries to:

Duncan Hardie
Manager, PERD
Office of the Science Advisor
Environment Canada
(819) 953-7625

▸ Additional copies of this publication can be obtained at no charge from:

Office of the Science Advisor
Environment Canada
Ottawa, Ontario
K1A 0H3

▸ Design Considerations: This report is printed on recycled paper using vegetable-oil based inks. It is bound with a metal spiral which is easier to remove in the event that it is recycled.

▸ Acknowledgements: The support and contribution of all individuals and agencies involved in this publication are gratefully acknowledged.

Coordination: Suzanne Roussel

Editing: H. Burgers and Associates Ltd.

Cover Design: Turquoise Design Inc.

Photo Credits: Energy, Mines and Resources Canada
Environment Canada
Fisheries and Oceans
Industry, Science and Technology Canada
Karol Kovacs, personal collection

▸ **Cette publication est aussi disponible en français sous le titre:** ***1990-91 Rapport annuel: programme recherche et développement énergétiques.***

CONTENTS

FOREWORD 1

EXECUTIVE SUMMARY 3

RESEARCH HIGHLIGHTS

- ENERGY EFFICIENCY 5
- COAL 11
- RENEWABLE ENERGY 15
- GENERIC ENVIRONMENT 19
- ALTERNATIVE TRANSPORTATION FUELS 23
- OIL, GAS AND ELECTRICITY 31

FINANCIAL PROFILE 1990-91 43

ANNEXES:

- ORGANIZATIONAL STRUCTURE 45
- ENERGY-ENVIRONMENT SPECIALIST ROSTER 46
- WORKSHOPS, CONFERENCES AND SEMINARS 49
- TECHNICAL REPORTS AND CONFERENCE PAPERS 50

FOREWORD

As its contribution to Canada's Federal Energy Research and Development Program, Environment Canada assists other departments and the industrial sector in understanding the environmental impacts of using traditional energy sources and in developing sustainable energy options. The particular expertise of its scientists is directed towards research and development which will:

- characterize pollution from the production and use of energy sources;
- assess new technologies for the treatment and reduction of waste streams, such as emissions, effluents and solid waste;
- contribute to higher standards of environmental protection and human health and safety through energy regulations; and
- provide environmental information on issues such as hydrology, climatic systems, meteorology, and renewable energy sources.

To transfer this knowledge, Environment Canada has sponsored, in co-operation with other partners, more than 10 conferences, seminars, workshops and courses held across Canada and abroad. Also, more than 150 publications document the results of the energy research and development activities.

This report presents some of the highlights of the results achieved by this collective scientific effort in 1990-91.

Dr. A.J. Chisholm
Science Advisor

Energy R&D Program Objective

The federal Energy Research and Development Program (PERD) is an inter-departmental program that deals with all aspects of energy research and development (R&D), except nuclear fission. The formal objective of the program is to:

> *develop the science and technology for Canada to produce and utilize its energy resources in an environmentally responsible and cost-effective fashion.*

In fulfilling this objective PERD seeks to:

i) sustain a diversity of environmentally compatible energy development and end-use efficiency options;

ii) balance regional interest and R&D needs;

iii) support R&D for the short, medium and long term;

iv) encourage maximum participation by the Canadian private sector and provincial governments; and

v) contribute to the technical base which will enhance the competitiveness and productivity of Canadian industry.

EXECUTIVE SUMMARY

The cornerstones of Canada's energy policy include: the conservation and efficient use of Canada's existing energy resources; the prevention, control or remediation of any environmentally undesirable impacts resulting from their use; and the search for alternative sources of energy and new technologies, to render their utilization of them safe, cost effective and competitive.

The main instrument for the development and management of national energy policies is the federal government's Energy Research and Development Program, in which Environment Canada is a prominent participant. Together with participating government agencies on the Interdepartmental Panel on Energy Research and Development (PERD) and other contributors such as industry or provincial agencies, Environment Canada promotes research in the areas of pollution control, waste management and human health and safety. While priority is placed on direct environmental concerns, Environment Canada, through PERD, also plays a role in ensuring environmentally-sound energy development, through the use of alternative transportation fuels, and renewable energy sources.

The Program deals with seven broad energy areas called Tasks. These are:

- Task 1 - Energy Efficiency
- Task 2 - Coal
- Task 3 - Nuclear Fusion
- Task 4 - Renewable Energy and Generic Environment
- Task 5 - Alternative Transportation Fuels
- Task 6 - Oil, Gas and Electricity
- Task 7 - Coordination and International Participation

Environment Canada is involved in a range of activities, in support of Tasks 1, 2, 4, 5 and 6 of the Program. Its specific expertise has been directed to:

1. development of waste management and emission control technologies to minimize pollution resulting from traditional energy use; and the development of regulations and guidelines to ensure that these controls are implemented;

2. exploration of alternative energy sources;

3. research on the environmental impacts of alternative energy processes or products; and

4. improvement of the safety of offshore oil and gas exploration through a series of projects concerned with the effects of water and marine conditions on offshore facilities.

This report provides an overview of Environment Canada's Energy Research and Development Program as it relates to PERD. It highlights research projects directly associated with Panel resources, but does not cover energy-environment programs which are solely funded through Environment Canada's A-Base resources.

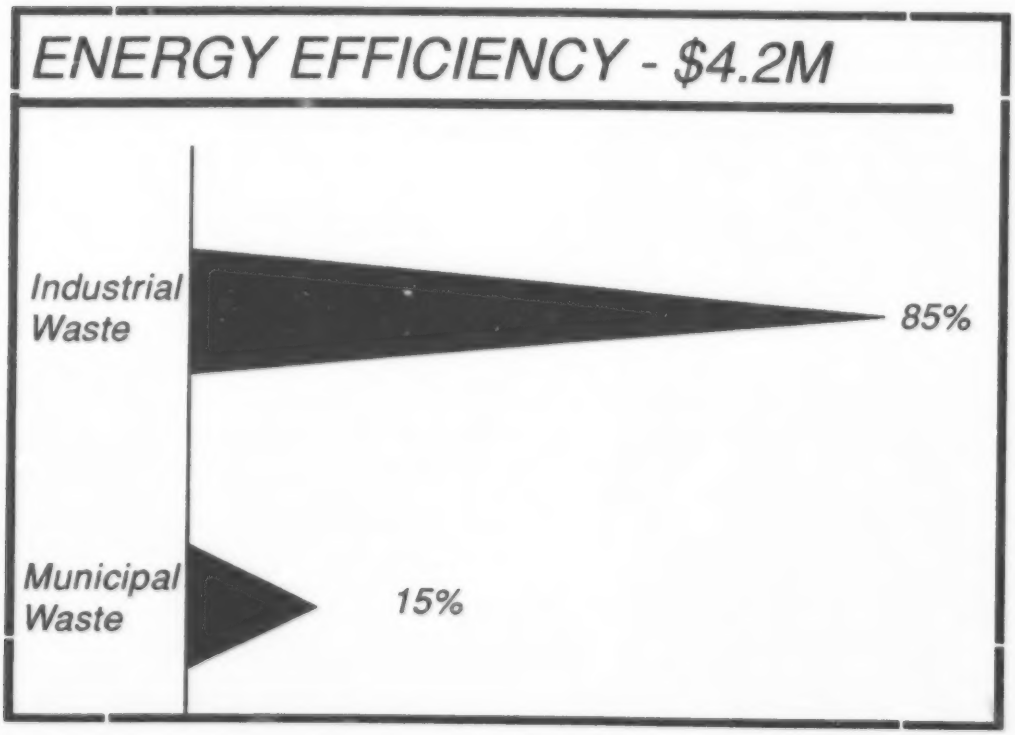
Financial and Person-Year Disbursement

In 1990-91, the total resources allocated to all participating Departments amounted to $91.2M and 202 PYs. Environment Canada's portion amounted to just over $7.2M and 15 PYs. In addition to the Energy R&D Program expenditures, Environment Canada's contribution from A-Base budgets amounted to $4.2 M and 42 PYs. The assistance of provincial research institutions, the private sector, universities and international institutions amounted to $3.8 M. The total expenditures associated with Environment Canada's Energy R&D Program totalled approximately $15.2 M and 57 PYs.

TASK 1: ENERGY EFFICIENCY

This section of the PERD program is concerned primarily with research and development aimed at increasing the efficient use of energy in all sectors of the economy. It addresses the conservation of existing resources by optimizing technologies for energy use in industries which are energy intensive; the development of technologies which reduce the environmental impact of conventional fuel utilization through emission controls and the improved handling of waste products; and the investigation of new methods for waste reduction and recycling.

Environment Canada receives approximately 9% of the total funding which PERD directs to the energy efficiency task. The Department's principal efforts in this area have been directed toward improved waste utilization and technologies to mitigate the environmental impacts of industrial and municipal processes through improved emission control processes. Research projects conducted under programs such as DRECT - Development and Demonstration of Resource and Energy Conversation Technology, and NITEP - the National Incinerator Testing and Evaluation Program, have made Canada a world leader in mass burning and emission control technologies and waste reduction. Other initiatives in this area have resulted in highly successful demonstration of technologies which reduce the energy cost of disposing of sewage sludges by improving processing systems at sewage treatment plants.



RESEARCH *HIGHLIGHTS*

Development and Demonstration of Resource and Energy Conservation Technology Program - (DRECT)

The DRECT program is a cost-shared program, working with industry, the private sector, provincial agencies and municipalities on jointly-funded projects to develop technologies for waste management, energy efficiency and resource conservation. The Program obtains funds from both PERD and Environment Canada. Proposals may be funded to a maximum of 50% of the estimated project cost with the level of support varying according to the economic, technological risks and potential energy benefits of the proposal.

Research projects completed under the auspices of the DRECT program in 1990-91, which come from all regions of the country, include the following:

▸ Management of Hospital Wastes

An estimated 550,000 kg of wastes are produced in hospitals in Canada every day. Only 10-15% of these wastes are potentially hazardous and require special treatment and disposal. The rest are land-filled which contribute to an already severe shortage of landfill sites. Moreover, to produce replacement materials requires more energy than to recycle reusable ones.

To identify the extent of this problem, Environment Canada has been involved in a project to inventory the amount and type of waste produced at the Ottawa General Hospital. The project also investigated the ways in which the waste is handled as well as its potential for reduction, reuse or recycling, and identified available markets for recycled materials.

Information collected in this project will be used to develop a standardized waste audit process to facilitate the implementation of waste reduction practices in hospitals, which will be both safe and efficient.

▸ Packaging from Reprocessed Materials

The objective of this project, conducted in collaboration with Pacware Systems of Ottawa, was to demonstrate that packaging products, acceptable to high - technology industries, could be produced by incorporating a proportion of plastic, recycled from some of the 823,000 tonnes of plastic waste which are land-filled in Canada every year.

The project confirmed the technical and economic feasibility of using plastic with a high percentage of recycled resin in the production of packaging material. The diskette packaging product was judged satisfactory with respect to general appearance, durability, functionality, crush resistance and temperature resistance. Pacware estimated a potential saving of $4,000-5,000 a year for small manufacturers using PVC containing reprocessed material.

▸ **"Superwood" from Recycled Plastics**

With funding from both the PERD program and the Ontario Ministry of Environment, this project demonstrated a new technology for producing a product called "Superwood" from mixed plastic waste, collected through the Mississauga "Blue Box" program. Superwood has properties similar to that of dense hardwood and can be worked with conventional wood-working tools. It can be used in fencing, crash barriers, planters, benches and has a variety of other commercial applications. Structural and durability tests have been conducted on Superwood products and the results indicate that it provides certain benefits compared to wood products. To date, the majority of sales have been to private industry but it is hoped to extend the market to various municipalities and government departments. This project is making a major contribution to the development of plastic recycling technology, which is essential for the success of the "Blue Box" program.

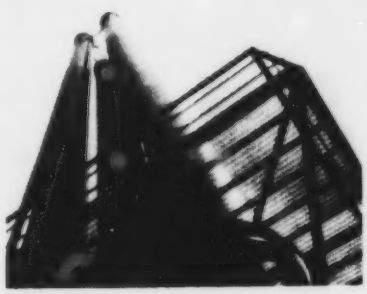
▸ **Mediaflex Filter System**

A variety of cost-sharing partners have been involved in this project, which demonstrates a technique for the improved treatment of septage using the Mediaflex filter process. This low technology, low-energy consuming system is based on a combination of filtering materials which act synergistically. The first layer removes pollutants; the second removes organic matter, metals and colour; the third layer is sand which retains solids and, being porous, allows for better drainage, thus reducing the risk of clogging the filter.

Using this process treatment for sewage, removals in excess of 95% were achieved for oil and grease and heavy metal contaminants, such as cadmium, cobalt, iron, lead and zinc. Precise costs depend on the volumes treated and are marginally higher than current rates for septage removal and disposal. However, local governments recognize that increased costs are inevitable if proper septage handling methods and their ensuing environmental benefits are to be achieved.

The National Incinerator Testing and Evaluation Program (NITEP)

In 1984, Environment Canada began the National Incinerator Testing and Evaluation Program (NITEP). This program was intended to address the increasingly grave problem of disposing of municipal garbage, by working with industry to develop technologies for burning these wastes in a manner which would significantly reduce air emissions and residual ash. An important element of this project was to demonstrate that it can also be used to generate energy, while effectively reducing the volume of waste going to landfill sites by up to 90%. The energy produced from incineration can be used to make steam for heating and industrial processes or directly into electrical power. In the NITEP program, which is funded in part by PERD funds, Environment Canada worked directly with industry, municipal and provincial governments and international organizations to define the best design and operating conditions to minimize harmful emissions from municipal waste incinerators.



A major highlight of the program in 1990-91 was the completion of a project on Refuse Derived Fuel (RDF) incinerator technology at a facility owed by the Connecticut Resource Recovery Authority in Hartford, Connecticut. This facility processes up to 1800 tons of waste per day from 44 communities in the greater Hartford area.

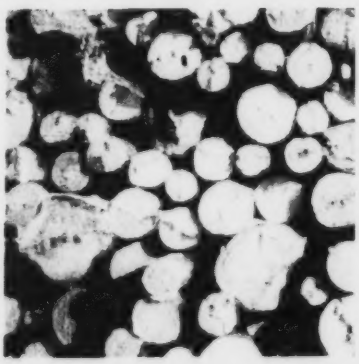
In co-operation with the US Environmental Protection Agency, (EPA), NITEP engaged in the most extensive evaluation ever undertaken of a RDF incinerator technology - a process that consists of preparing the waste, prior to burning.

RDF processes begin with the manual sorting of wastes and proceed through shredding, separation and screening stages to improve the combustion process and to recover recyclable materials, such as metals and glass. Following the incineration stage, the resulting flue gases flow through a two-stage air pollution control system, prior to release through a stack.

Under NITEP it was demonstrated that an RDF incinerator equipped with an air pollution control system can control significantly the flue gas emission. Test results show that, due to the control system, the total dioxin and furan emissions were much lower than Canada's standards - a removal rate of more than 99% of these two organic compounds. As well, the RDF system was able to remove most metals emissions at a rate of more than 99 %.

Sludge Incineration at a Pulp Mill Power Boiler

Another area where incineration may prove to be an answer to an acute environmental problem is in the disposal of sludge, resulting from the operation of pulp and paper mill processes. This sludge contains high levels of dioxin, furans and other chlorinated organic compounds and is often disposed of into the environment through landfills or ocean dumping. Once proved environmentally sound, incineration would offer an attractive alternative.



In 1990-91, under the PERD program, the Pacific & Yukon Region of Environment Canada conducted the first comprehensive emission test of a recovery boiler in Canada, at Howe Sound Pulp and Paper Ltd., Port Mellon, B.C. The recovery boiler, which became operational in 1990, represents the latest technology in its field. At 390 tonnes of steam per hour it is also one of the largest units of its kind in North America. The emission test data provided important information for the first time on toxic air contaminant emissions from these process units. The stack testing included standard fuel gas parameters, metals, semi-volatile compounds (including dioxins and furans) and volatile compounds.

Optimization of Sludge Processing Systems

Previous research, funded under the PERD program, has demonstrated that energy savings are achievable at sewage treatment plants by incorporating optimized process control strategies. The overall sludge processing procedures, which may include primary clarification, digestion, dewatering, thermal drying, combustion and conversion are energy intensive. However, the correct coupling and optimization of these separate procedures can result in significant energy and capital cost savings. Through optimization of sludge management systems, it is projected that national energy savings of about $15 million per year could be realized.

This project, which is being conducted at the Wastewater Technology Centre in Burlington, Ontario, aims to develop and demonstrate a methodology for auditing sludge processing systems to identify areas where the installation of state-of-the-art sludge instrumentation and control technology could result in significant improvements and cost savings. For example, mechanical modifications have been made at the Banff sewage treatment plant to facilitate the installation of new on-line instrumentation for the monitoring of treatment processes.

Traditionally, major operational changes in sludge processing have been made in the processing of the liquid train, with only minor consideration being given to the potential impact on the solids train. New research aims to refocus this approach and establish control strategies which will identify the relative importance of both the solid and the liquid train in achieving overall energy efficiency in wastewater treatment processes.

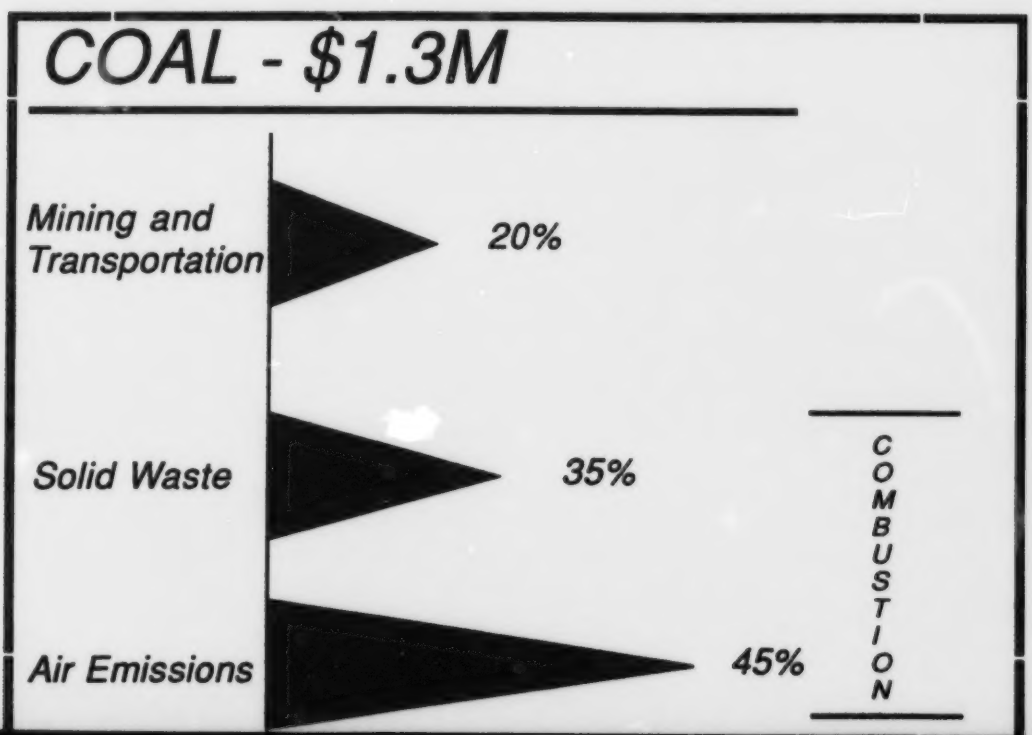
TASK 2: COAL

Other tasks, within the PERD program, address the issue of developing, over the long term, alternative sources of energy, both for transportation and for domestic and industrial use. Task 2 deals specifically with the nearer term potential of using an indigenous, abundantly available fossil fuel, coal. Environment Canada is the lead department in research and development into technologies to permit the full utilization of this resource in an environmentally acceptable fashion, thus supporting the principle of sustainable development.

This area of research is of particular interest to Atlantic Canada. Nova Scotia, for example, is committed to reducing its dependence on offshore oil by increasing the use of indigenous coal. Existing oil-fired generating plants are being replaced by new coal-fired units, while new generating plants are expected to be coal-fired. However, the use of coal as a major energy source has resulted in detrimental impacts on the environment, causing acidic depositions, smog and global warming. Waste disposal problems present further difficulties and new technologies are necessary for better management of both combustion process residues and coal mining rock waste. Finally, there is need for adequate environmental protection and safety standards in the operation of mining facilities.

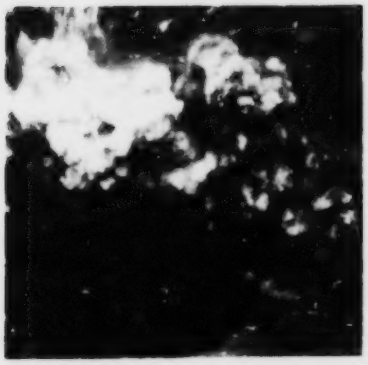
These problems are particularly acute in the light of Canada's international commitment, as a signatory to the Economic Commission for Europe (ECE) protocol, to freeze emissions of nitrogen oxides (NO_x). As well, federal/provincial initiatives are in place to reduce sulphur dioxide emissions by 50% and the International Climate Change Conference held in Toronto in June 1988 suggested a 20% reduction in CO_2 emissions.

PERD devotes about 6% of the resources of the coal task for research projects carried out by Environment Canada. These project address the issues of cleaner coal technologies; more efficient utilization; and seek solutions to reduce the environmental effects of coal mining, preparation, and transportation.



Treatment of Wastewater from Surface Coal Mines

The Canadian coal mining industry releases large amounts of nutrients, especially nitrogen, from mining and milling operations. Excessive amounts of nitrate, nitrite and ammonia can cause significant aquatic degradation.



A pilot project has been conducted at Quinsam Coal Ltd's mine, near Campbell River on Vancouver Island, British Columbia, to evaluate the use of wetlands in treating nitrate enriched, coal mine wastewater. The objective of this program was to quantify the removal of nitrogen and phosphorus from wastewater through the use of emergent aquatic plants, as affected by the season of the year.

This has been a three year project and the field work is now completed. The results show that seasonal temperatures significantly affect biological activity but that physio-chemical and biological nitrate removal mechanisms, in an artificially constructed wetland during the growing season, can reduce nitrate concentration by over 90%. As a result of field sampling, a final report will include the design criteria for a full-scale artificial wetland wastewater treatment for at coal mines.

Coarse Coal Refuse Management

Coal contains pyrite and other reduced forms of sulphur which oxidize to sulphuric acid when exposed to air and water. The near absence of buffering capacity in Maritime streams and lakes leave these waters unable to resist any conditions, such as the leachate and seepage from these coal wastes, which lower the pH. In addition, this acid leaches heavy metal contaminants such as iron, aluminum, arsenic, manganese, copper and zinc from the waste rock, further impacting the receiving waters.

As part of a study funded by PERD, a pilot project to assess cost-effective methods and technologies to prevent, reduce or treat this acid generation in coal waste was carried out at the Victoria Junction Coal Preparation Plant in Cape Breton. Based on the report prepared in 1989-90, three alternative techniques for the management of coarse coal rock waste were selected to undergo further evaluation in a pilot study. The present method of straight-end dumping and levelling of the waste has proved to create an ideal condition for an acid-generating environment.

In this project, small test plots will be created adjacent to the present waste rock dump and each plot will be tested with different technique for managing residual wastes.

Future plans for this project include demonstration of tested technologies to the coal industry in New Brunswick, other parts of Nova Scotia and British Columbia. The eventual transfer of such remedial technology to coal preparation plants, which reduces the sulphur content, will result in a more environmentally sound utilization of coal as an industrial fuel.

Advanced Coal Combustion Control Technologies

Under this program, two major projects are underway. One investigates technologies for the management of solid wastes and effluents which are by-products of coal utilization. The other deals with the control of gaseous emissions, including acid gases, nitrous oxides and greenhouse gases which contribute to acid rain, smog and global warming respectively.

▸ Management of Solid Wastes and Effluents

The first project studies ways of managing by-products resulting from a technology known as fluidized bed combustion (FBC). This technology consists of burning coal particles in a bed of limestone, which reacts with sulphur dioxide gases to form by-products that can be removed with ash residues. Nitrogen oxides gases are controlled by the boiler's air-flow conditions. Partners in this project, carried out in Chatham, New Brunswick, include private companies such as the Dearborn Chemical Co. Ltd, the Canadian Electrical Association and the Power Corporations of New Brunswick and Nova Scotia.

The project has assessed the characteristics of the residues and the environmental implications of FBC wastes and wastewaters and has developed and demonstrated environmentally appropriate waste disposal procedures. It has also developed promising new procedures for utilizing FBC residues to produce either a synthetic aggregate or a concrete, which can be used in road base construction.

▸ Control of Gaseous Emissions

A companion project is investigating emission control technologies for fossil-fuelled boilers and is developing advanced combustion and power generation technologies which have superior environmental performance. Based on this research, government and industry can develop cost-effective emission control strategies and standards.

In Europe and Japan, Selective Catalytic Reduction (SCR), using ammonia, has been demonstrated to be very efficient in reducing NO_x (nitrogen oxides) in the flue gas from fossil-fuelled, utility power boilers. Tests has been conducted by MONENCO consultants of Calgary, Alberta, to assess the possibility of using this technology in Canada. Similarly, Sypher: Mueller Intl. (SMI) of Ottawa conducted a study on the full-fuel cycle emissions of greenhouse gases from coal use, indicating the need for further research on the environmental impact of large-scale CO_2 disposal on land or in the sea, and on the contribution of minor trace gases from the coal cycle to global warming.

Finally, Environment Canada co-funded a project, conducted by Fenco Shawingan of Halifax, N.S., on the feasibility of collecting coal mine methane (which would otherwise be vented to the atmosphere) and piping it to a coal-fired utility boiler for incineration and heat recovery. On a per molecule basis, methane is 30 to 50 times more powerful a greenhouse gas than CO_2 and, consequently, technologies for its recovery and use in this manner are environmentally beneficial.

Development of Sampling and Analytical Methods for Coal in a Particulate Matrix

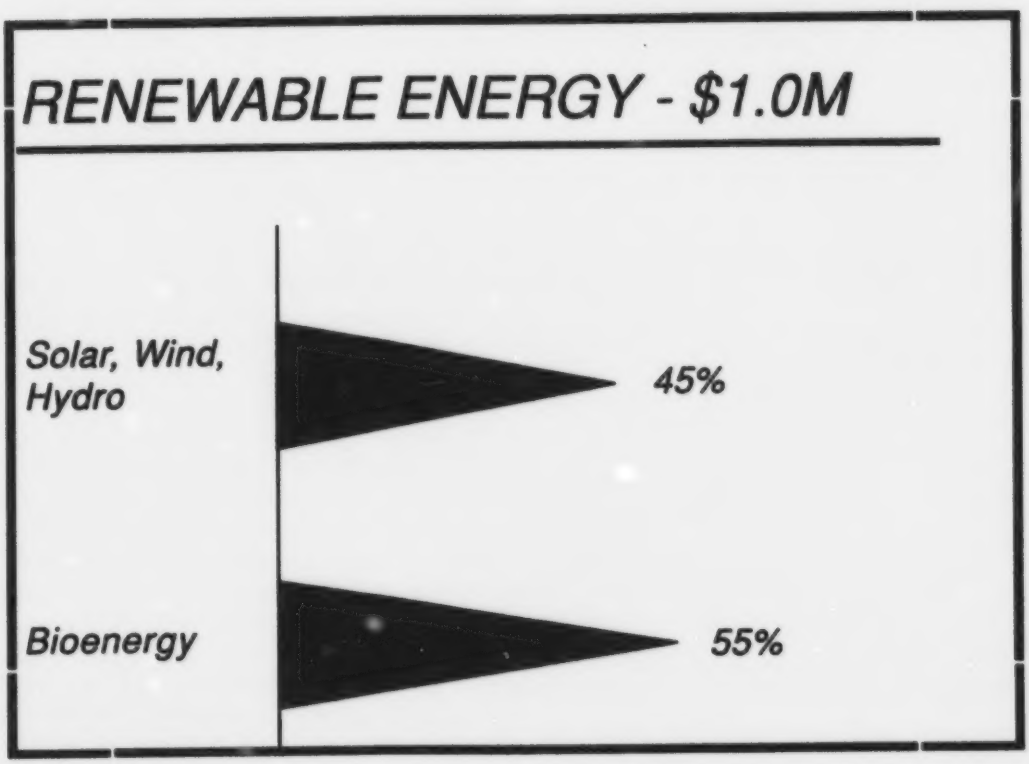
Over 25 million tonnes of thermal and metallurgical coals are exported annually through three tidewater terminals on the west coast. Major quantities of B.C. and Alberta coals are also shipped east to thermal generating plants in Ontario. Transportation and storage of this coal is a major source of airborne pollution. Since the early 1980's, studies by Environment Canada, supported by PERD funding, have focused on evaluating methods of mitigating coal dust contamination during the transportation process.

In this project, research is focused on the development of ambient air particulate sampling equipment which will capture coal dust particles. This is the basis for developing analytical methods to determine the fraction of coal in a dust fall sample. Preliminary experimental work has been conducted using two techniques - pyrolysis gas chromatography and solvent extraction, followed by high performance liquid chromatography measurement. The solvent extraction method is capable of measuring 5% coal in a 5 mg sample, but possible interference by diesel soot presents a problem. Work on a solution to this problem is now in progress. The pyrolysis gas chromatography method is also susceptible to similar interference by diesel soot and does not produce as sensitive an analysis. In addition, two ambient particulate monitors have been tested to determine their reliability under field conditions in establishing coal dust concentrations in the air.

The measurement and analytical research conducted out under this project will make a major contribution to the development of acceptable control standards and methods for monitoring compliance. This is becoming increasingly important since the development of new coal reserves in northwest British Columbia has caused renewed concern over the air quality impacts of rail transportation and coal terminal operations. In addition, a projected increase in the use of lower sulphur coal in Ontario underlines the need for improved environmental controls in the coal fuel-cycle.

TASK 4: RENEWABLE ENERGY

Tasks 1 and 2 of the PERD program deal with the development of technologies which assist in the most efficient and environmental benign use of traditional energy sources and the disposal of potentially harmful by-products. The objective of Task 4, however, is to complement this work by research on technologies to harness new and renewable energy resources - wind, solar, biomass and hydro. R&D projects on renewable energy aim to exploit these resources and, thus, to provide options for a sustainable energy base in the future. In addition, research and development undertaken in Task 4 is investigating new bioenergy technologies such as the production of methane which will utilize anaerobic digestion in the disposal of waste by-products.



Hydraulic Design Methodology for Small-Scale Hydro-Electric Developments

Environment Canada has a mandate under the Canada Water Act to undertake research and establish technology for the best management of national water resources. The Federal, Water Policy, released in 1987, pledged the government to continue to contribute to research and development into technology to utilize small-scale hydro potential, which is widely accepted as a practical, environmentally benign and viable renewable energy resource.

One of the main concerns in the development of small-scale hydro projects is that the high cost of determining their potential energy production calls into question their economic viability. A cost-effective hydrologic methodology to determine flow availability and flood magnitude at potential, but ungauged, sites could considerably reduce uncertainty about their development and assist potential developers to reduce the cost of determining the most promising sites for small-scale hydro projects.

Through the PERD program, Environment Canada is involved in a multi-year project to develop methodologies which can determine valuable flow for electricity generation at potential sites and to incorporate these methodologies into computer models which can be used to conduct feasibility level studies in various regions of Canada.

In 1990-91, work on this project focused on developing a hydrological design methodology to determine flood magnitudes at ungauged small-scale hydro sites in Quebec through a regional flood frequency analysis. Success with these projects will provide the basis for further development of the model in subsequent years.

Design Information and Measurement Technology for Solar Energy

The principal objective of this project is to provide solar energy resource information to assist the design, planning, deployment and operation of solar resources and building energy systems through standards development.

Environment Canada, in partnership with Dartside Consulting of Ottawa and the WATSUN Simulation Laboratory at the University of Waterloo, is involved in a five year project to develop and implement effective modelling procedures for atmospheric radiation parameters, as these are applied in solar energy design; using R&D and the adaptation of new technology to improve solar radiation and energy measurement capability; assisting Canadian industry in developing and marketing new technologies in this field; and helping agencies that set standards to ensure that they are implemented.

Findings, resulting from the research, will aid in the choice of sites and determination of optimum size for solar collectors and in giving direction to the R-2000 building program. New databases of spectral and directional distribution of irradiance will be used in new and sophisticated models being developed for building window and energy system design.

BIOENERGY: Methane Production from Industrial Wastewaters

The overall objective of this project is to develop and demonstrate anaerobic methane biotechnology, which can be used to provide energy efficient full-scale treatment of complex toxic industrial wastewaters. Over the past decade, the Wastewater Technology Centre in Burlington, Ontario has developed considerable expertise in anaerobic treatment, which uses a biological fermentation process that converts organic pollutants from wastewater to usable methane gas.

Early efforts in this project were directed toward the easily biodegradable wastewater produced by the agrifood sector. With support from the PERD program, research emphasis has shifted to addressing the more complex issues posed by wastewater produced by the pulp and paper industry.

Environment Canada's anaerobic biotechnology program extended the application of energy-efficient treatment technology to toxic and inhibitory industrial wastewaters. The pulp and paper industrial sector was selected as the vehicle for this phase of the work. Calibration and verification studies were completed on the previously developed anaerobic process control. The fate of resin acids from CTMP wastewaters in anaerobic treatment systems was evaluated. Their impact on, and mitigating measures for the maintenance of process efficiency were assessed and a report was completed. Experimental investigations on the feasibility of high rate anaerobic dechlorination on methane production for Kraft bleach plant effluents were also completed. A report is under preparation for delivery in 1991-92. The pilot scale anaerobic study at the Western Pulp Partners, Port Alice, BC mill was completed, as defined.

WIND: Atmospheric Aerodynamics

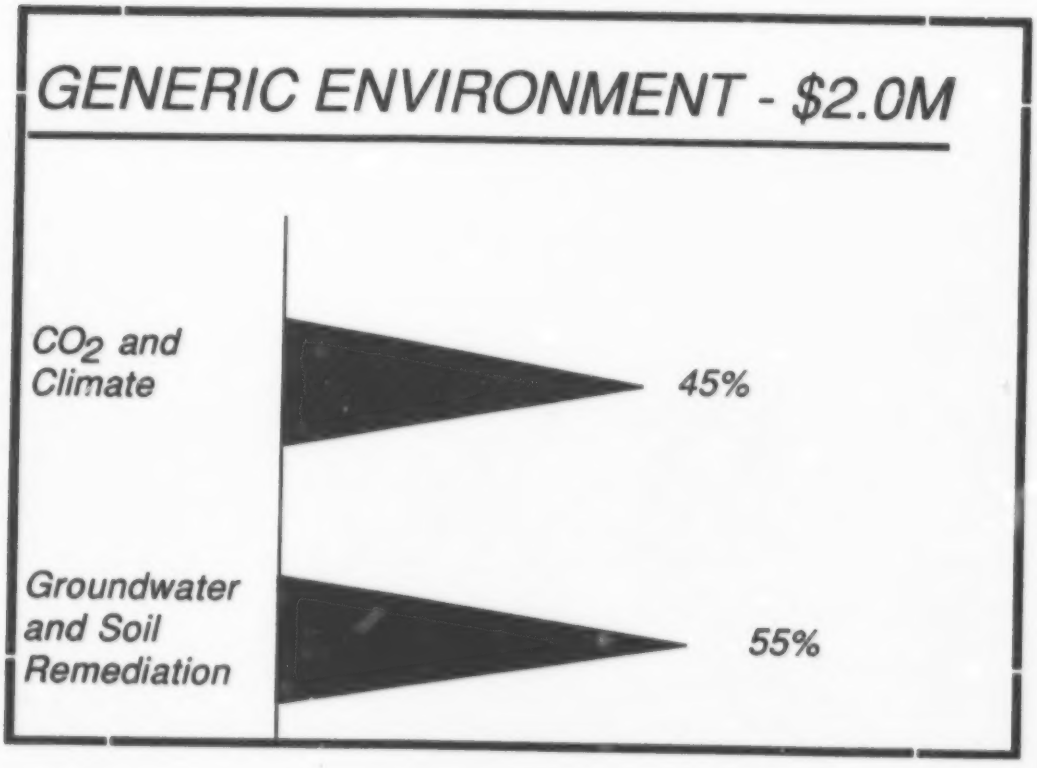
This ongoing project is concerned itself with research and development of computer models, climatological data and methodologies, which can establish the feasibility of utilizing wind energy resources at potential sites for wind energy conversion systems (WECS). It aims to establish techniques which can characterize wind resources in such places as exposed coasts, remote locations, mountains passes and ridge tops, where physical observations are difficult or impossible to obtain.

During 1990-91, in cooperation with several private contractors and the WATSUN Simulation Laboratory at the University of Waterloo, the project continued with basic research into boundary layer over terrain features, including full-scale measurements and mathematical and wind tunnel modelling; and on developing a comprehensive wind energy atlas for Canada.

TASK 4: GENERIC ENVIRONMENT

A major responsibility assumed under Task 4 of the PERD program is to continue an overall research and information function on generic environmental issues which might result from utilization of both new and conventional energy sources; and to co-ordinate activities which contribute to national policy objectives of both energy security and environmental protection. It investigates and reports on any major environmental issues which might result from energy systems, whether in the field of conventional energy use, or from new or innovative energy development. In particular, it has been concerned with the probable impacts of global-scale combustion of fossil fuels on climate and with the assessment of the implications for climate change of radiatively active gases (RAGS), produced by energy consumption. In addition, it investigates and develops remediation technologies for the restoration of groundwater and soil, contaminated by the activities of the petroleum industry.

Global scale combustion of fossil fuels is likely to result in a doubling of carbon dioxide (CO_2) concentrations within the next century. These concentrations, when added to those of other lesser trace gases, are expected to cause a major global warming unprecedented in human history. Although there are still scientific uncertainties surrounding the issue, it is emerging as, perhaps, the most important global environmental issue of the century and is already a major consideration in domestic and international energy policies.



RESEARCH HIGHLIGHTS

Carbon Dioxide Advisor

The objective of this project is to develop and make available to government policy makers, specialized information on global warming caused by increasing concentrations of greenhouse gases from energy utilization, particularly carbon dioxide; and to advise on related implications for energy supply and demand in Canada. An ongoing project, the program focuses on the development and dissemination of international scientific knowledge pertaining to energy related emissions of greenhouse gases and the co-ordination of Canadian research on a range of projects related to climate change. Major highlights of the 1990-91 projects included the planning and convening of a workshop on Canadian research on sources and sinks of greenhouse gases and production of the section on climate change for inclusion in Environment Canada's State of the Environment Report.

Radiatively Active Gases Measurements

Changes in the spectral distribution of the atmospheric radiation balance are the primary response of increased radiatively active gases. This change in the spectral distribution of energy induces climate change. However, due to the inertia of climate caused by delayed ocean response, changes in the atmospheric radiation balance precede actual climate change by about 50 years. This ongoing project is aimed at developing methodologies that would monitor these changes in the atmospheric radiation balances, for the purpose of early detection of impending climate change. As the work has progressed over the last ten years, it has established Environment Canada as a world leader in obtaining information on climate change using radiative technologies.

The project started in the mid-eighties with Environment Canada funding to establish an observatory platform. PERD funding commenced in 1988-89, when the observatory became operational, and has enabled it to increase its instrumentation and improve the quality of data collection. 1990-91 represented a year of solid achievement, during which, in co-operation with Scientific Instrumentation Ltd of Saskatoon and York University, measurements of shortwave and long-wave fluxes were continued; the on-site computer system was upgraded to facilitate more complete data acquisition and analysis; payloads were flown from the Vanscoy balloon flights; and the Michelson balloon interferometer was tested and modified for ground-based infrared spectral measurements.

Carbon Cycle and Climate Modelling

The third project dealing with carbon dioxide and global warming is directed at improving the models which are used to predict climate change. In particular, it is involved in developing a global climate-carbon cycle model for estimating the rate of increase in the surface temperature of the earth, due to the year-to-year increase in atmospheric CO_2 levels.

This ongoing project will contribute to a better understanding of the feedback mechanisms controlling CO_2 fluxes among the major carbon reservoirs in the world, while information derived from it would serve as a key variable in the development of future Canadian energy policies.

A global two-dimensional (vertical and north-south) model of the climate - CO_2 cycle is under development. Major carbon reservoirs will be included and major known interactive processes between the climate system and the global carbon cycle will be parameterized and included in the model. In particular, the model will include the marine biological component of the global cycle, since it is hypothesized that this component is one of the key mechanisms which caused the close relationship between CO_2 and temperature during the last glacial-interglacial cycle.

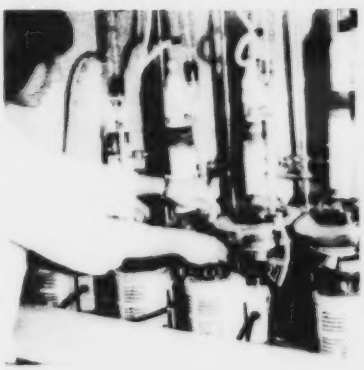
Groundwater and Soil Remediation Program

The Groundwater and Soil Remediation Program (GASReP), established as a government-industry venture in 1989, supports PERD's aims to provide the science and technology to support a diversified, environmentally sustainable, energy.

Within its broad context as an initiative for research, development and demonstration of innovative clean-up technologies, GASReP targets basic applied research and/or technology development only.

Industrial partners and other government programs are encouraged to extend GASReP's research funding to the final stage of technology demonstration. Currently, GASReP focuses on environmental issues linked to the petroleum industry.

This PERD program is managed by the Wastewater Technology Centre in Burlington, in co-operation with a number of industrial partners, including Ortech International, Droycon Bioconcepts Inc., CH2M Hill, engineering and consulting firms, such as Beak Consultants and Marbek Resource Consultants, and the University of Waterloo.



It focuses on remediation technologies in one of the following four categories under consideration - *in-situ* bioremediation; volatilization of the organic carbon compounds and subsequent treatment of the off-gas; excavation and subsequent treatment of contaminated soil; and the pumping out and remedial treatment of contaminated surface and groundwater sources. Treatment technologies, involving biological, physical/chemical, and residue management processes are being developed and tested at bench-scale and demonstrated at pilot scale in the field with the eventual objective of full-scale, on-site treatment plants.

During 1990-91, projects on literature review of technologies, research, and technology transfer were completed. These reviews resulted in three reports on state-of-the-art of remediation technologies in the areas of excavation and treatment of contaminated soil, enhancing volatilization of organic compounds in the unsaturated zone, and treatment of off-

gases. A fourth report examined considerations, limitation and the potential and future direction of *in-situ* bioremediation.

Work was completed on two research projects, but only one report was submitted. The University of Waterloo report, prepared for GASReP and the Canadian Petroleum Products Institute, examined using denitrifying bacteria for *in-situ* cleanup of benzene in groundwater. The other project dealt with laboratory studies on biological barriers to contain and remediate contaminated groundwater.

GASReP sponsored three technology transfer sessions to help enhanced knowledge in the field of remediation technologies. The three sessions included *Prevention and Treatment of Soil and Groundwater Contamination in the Petroleum Refining and Distribution Industry, Advanced Oxidation Process for the Treatment of Contaminated Water in Air,* and the *First Annual GASReP Symposium on Groundwater and Soil Remediation.*

Energy Technology System Analysis Program (ETSAP)

Canada is an active participant in Annex IV ETSAP, whose purpose is the use and development of the MARKAL linear programming model to develop and examine energy technology options to reduce the emission of greenhouse gases in national or provincial energy systems over a 45-year period.

The MARKAL software program is used to model the possible evolution of national, regional or provincial energy systems over a period of decades. The energy system is represented by alternative sets of typical existing and potential technologies that extract, convert, transport and use energy. Environmental requirements, technical feasibility and economics are set as constraints or objectives that impact upon the evolving energy system. The unique feature of the model is that it does not confine itself to forecasting the future, but rather evaluates a number of ways to influence it.

The MARKAL model is already being used by eleven countries in the IEA's ETSAP to examine technological options for meeting the threat of global climate change.

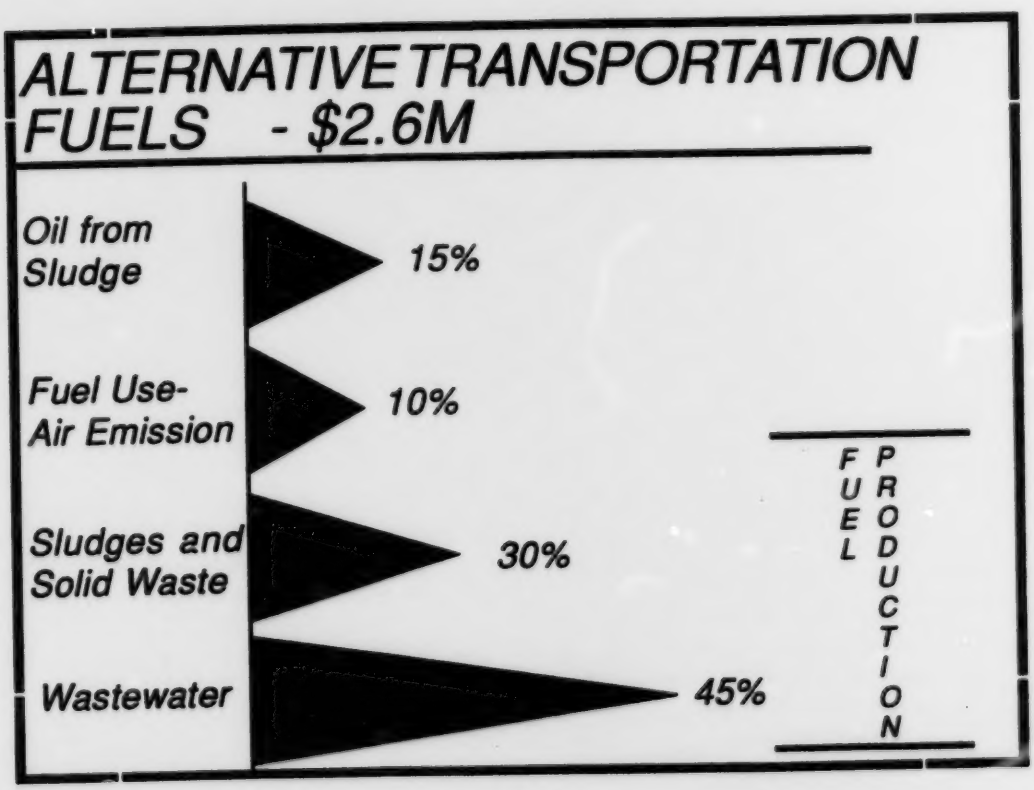
In Canada, with PERD support, MARKAL has been developed by Groupe d'études et de recherche en analyse des décision (GERAD), a joint research centre of three Montreal institutions. Early experience indicated that the Canadian energy system was too diverse to be represented in a single aggregated model. GERAD, therefore, initially focused on developing a model of Quebec, as the basis for developing other regional and multi-regional models.

In 1990-91, ETSAP held two workshops which reviewed national options for future development of the province of Ontario and the first runs on reducing CO_2 in Quebec and Ontario were conducted. Based on the results of a 1991 workshop, plans are underway to extend the MARKAL model to British Columbia and Alberta. There was strong interest expressed internationally. GERAD is conducting MARKAL analyses in Tunisia and there are possibilities for extending the program to India, with International Development Research Centre (IDRC) and Canadian International Development Agency (CIDA) support.

TASK 5: ALTERNATIVE TRANSPORTATION FUELS

Environment Canada receives approximately 8% of the total funding which PERD directs to the alternative transportation fuels task. The Task's objective is to conduct research to enable a transition from traditional to alternative transportation fuels in the next century. It is concerned with new technologies to develop resources such as heavy oil, bitumen, natural gas and biomass, to provide reliable supplies of energy through diversification. It further conducts research and development to ensure that both the production and the use of such energy resources results in technology and practices which are environmentally benign. Such activity is particularly critical, since the transportation sector accounts for more than a quarter of Canadian domestic energy consumption and depends, almost entirely, on crude oil, accounting for about two thirds of crude oil demand. Western Canadian light crude oil is the major feedstock, but this supply is declining and alternate sources must be established throughout the exploration of non-conventional energy resources and the production and use of new liquid fuels.

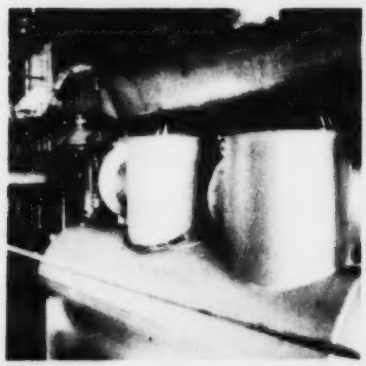
Environment Canada focuses on two areas of this Task: the first deals with the environmental impact of developing Canada's bitumen, heavy oil and natural gas resources, where the emphasis is on treatment technology development and application, the evaluation of controlled wastewater discharge, or disposal of waste products. While the second evaluates the environmental impacts of the end use of various new transportation fuels, as compared to conventional fuels. This involves extensive work in the area of emissions testing and subsequent development of regulatory standards to ensure acceptable levels for their control.



ENVIRONMENT: NEW LIQUID FUELS

Biomass and Solid Wastes - Liquid Fuel Production from Sewage Sludge

As part of the search for alternative transportation fuels, this PERD project has demonstrated that sewage sludge can be thermally processed to produce liquid and solid fuels. Laboratory tests indicated that a high quality, cost-effective liquid could be produced. Commercialization of the technology consequently began with the design of a one tonne per day pilot plant. The plant, which was constructed by Petro-Sun International (PSI), has been operating in Hamilton since 1987 and a 45 tonne per day full scale demonstration plant is being designed for Metro Toronto's Highland Creek facility.



During 1990-91, a contract was finalized between Metro Toronto and SNC Enersludge for the 45 tonne per day demonstration plant, thus removing a major obstacle to commercializing the technology. It is anticipated that a final report on the process performance and an environmental evaluation of the demonstration plant would address two potential objectives: new source of liquid hydrocarbon for the asphalt industry would become available and there would also be a potential solution to an existing environmental problem, the disposal of sewage sludge.

Emissions Testing in Support of Alternative and New Fuels Field Trials

There is a growing interest in limiting harmful emissions from the transportation sector by using cleaner fuels and engine combinations. However, before commercialization of low emission vehicles/engines which may operate on alternative and new fuels begins, it is essential to collect sufficient operational experience, durability data and confidence through field trial and demonstration programs. The results from emission testing obtained under this project, along with other results from field trials, should provide valuable information to government in setting emission standards and to the vehicle and fuel industries in developing low emission engines/vehicles.

This PERD program is involved in testing and evaluating the environmental impact of methanol as opposed to diesel-powered buses. Environment Canada conducted emissions tests on two transit buses in November 1990. The test vehicles included a Medicine Hat Transit Bus powered by a prototype methanol engine and an Ottawa-Carleton Transit Bus equipped with a comparable diesel engine. Both vehicles were essentially identical, except that one vehicle was equipped with a methanol version engine. The emissions assessment of both methanol and diesel engines provided a quick comparison of the environmental implications of these two fuels. The results indicated that methanol engines offered some significant advantages over diesel with respect to NO_x

and particulate emissions, but that CO emissions remained high. The engine manufacturer will be working on controlling these emissions through the use of an oxidation catalyst in later stages of the project.

Environmental Implications of Synfuel Processes

Canada is relying on heavy oil and bitumen production to assure self sufficiency in our long-term energy needs. However, unlike conventional crudes, heavy oils and bitumen contain significant quantities of heterocyclic nitrogen compounds (HNC) and heterocyclic sulphur compounds (HSC) - sometimes up to 25%. Some of the HNC's are carcinogenic and exhibit high aqueous solubility. For these reasons, their fate during heavy oil and bitumen processing and product utilization needs to be addressed and the environmental impact of these contaminants evaluated to ensure adequate control strategies are implemented.

This PERD project builds on findings from an earlier project which, by exposing products from synfuel processing to high temperatures (up to 1200 °C), allowed the products of such combustion to be identified and quantified. Staff from the Wastewater Technology Centre, working with Dearborn Environmental Consultants, are currently seeking to generate a comprehensive database on contaminants of concern in synfuel products and waste streams. As the project continues, control options and opportunities for further technology development will be identified.

Environmental Impacts of Alternative and New Fuels in Motor Vehicles

Automotive emissions continue to be the largest source of air pollution in Canada. This ongoing PERD project addresses the technical and environmental implications of using alternative and new transportation fuels on emissions from motor vehicles, as well as their subsequent impact on broader environmental issues, such as ground level ozone, the greenhouse effect and urban air toxics. This is providing a knowledge base for those departments, such as Transport Canada, which are involved in setting regulations. For instance, Canada is currently examining new motor vehicle emissions regulations that will be fuel neutral. This will provide vehicle manufactures and fuel suppliers with the opportunity to market any vehicle and fuel combination they deem appropriate, as long as it meets the emissions standards. Thus, future vehicles in Canada will be able to use a variety of fuels.

Over the past three years, activities under this project which included literature reviews, emissions testing of oxygenated and reformulated gasolines and other alternative fuels, and specification of hydrocarbon and aldehyde emissions have provided valuable information on emissions from motor vehicles using alternatives and new fuels under Canadian conditions. The highlight of 1990-91 was the conducting of emission tests on four similar vehicles which took part in the "World of Wheels" cross-Canada rally. The test fuels included gasoline, natural gas, propane and M85 (a mixture of 85% methanol and 15% gasoline). The test results, while not conclusive, indicated that alternative fuel vehicles offer promise as a means to reduce selected emissions. It should be pointed out that the M85 vehicle used in the car rally was an older model and does not represent the current model technology.

Emission Testing for Heavy-Duty Vehicles

The existing emission standards for heavy-duty engines in Canada are essentially the same as for the United States. However, the U.S. is tightening the particulate emission standards for heavy-duty engines. Canada will probably follow suit and set heavy-duty emission standards comparable to those in the U.S. In this ongoing project, Environment Canada has been performing emissions tests on heavy duty diesel buses and trucks to evaluate the potential emissions reduction that can be achieved with emerging heavy duty diesel engine technologies.

In one program, exhaust emission rates from diesel transit buses, provided by Ottawa-Carleton Regional Transport (OC Transport), Ontario Bus Industries Inc. and the National Research Council were measured. The results will serve as a baseline against which new technologies can be evaluated. Two examples are the emissions reductions attributable to the so called "clean" diesel engines, as well as to alternative fuel engines that are now under development.

One example of comparative engine testing is provided by the Navistar "smokeless" diesel, on which Environment Canada recently completed emissions testing, in anticipation of the pending 1994 heavy diesel engine particulate standards in the U.S. Test results revealed that the smokeless diesel provided a substantial reduction in regulated exhaust emissions. Testing also revealed that exhaust emissions are dependent on diesel fuel quality.

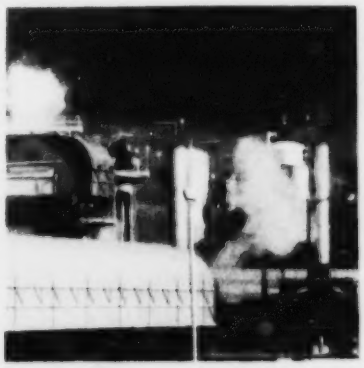
The results of this project will provide valuable information on actual emissions from engines in heavy-duty vehicles in Canada, using alternative fuels and different types of diesel fuels. This information will be of significant value to the federal and provincial governments in assessing and promoting the use of alternative transportation fuels, and to industry for improving engine design and emissions control technology. The results will also provide information to assist in developing Canadian emission standards for heavy-duty vehicles.

ENVIRONMENT-UPSTREAM OIL SANDS AND HEAVY OILS

A recent review of the Task 5 area revealed that synthetic oil production from heavy oil reserves was likely to be an important source of energy for Canada over the medium-term. This means that there is a need to develop an awareness of the potential environmental impacts of this activity and, in particular, to develop new technologies for the treatment of by-products and residual wastes from the recovery of non-conventional feedstocks, such as bitumen and heavy oil. Several projects are underway which address particular aspects of this problem.

Pollution Abatement Technologies: Bitumen/Heavy Oil Upgrading and Natural Gas Processing Wastes

Alternative hydrocarbon based fuels production, such as synthetic crude, liquified petroleum gas, propane and methanol will replace conventional crude oil, as conventional crude sources become depleted. This will result in a significant expansion of the heavy oil, bitumen and natural gas processing industries. Industry and government site assessment studies have identified numerous waste management concerns and environmental treatment technology gaps, related to an alternative hydrocarbon-based fuel processing operations. There will, for example, be a significant increase in liquid and solid wastes requiring storage, treatment and disposal at the processing plant sites. This will also lead to an increase in the number of hydrocarbon or process chemical leaks and spills which may contaminate groundwater aquifers and soil near the plants.



This multi-year PERD research program was developed to help mitigate these environmental problems. The major objectives include assessing sludge and solid waste management and developing control measures for plants producing alternative hydrocarbon-based fuels; determining the characteristics and environmental significance of the contaminants present in the waste associated with bitumen and heavy oil upgrading and natural gas processing facilities; and identifying and demonstrating technologies to treat priority waste from these facilities.

A highlight of the program has been a three-phased R,D&D program on subsurface remediation of soil and groundwater contamination at Alberta sour gas processing plants, initiated jointly with the Canadian Petroleum Association in 1989. It is anticipated that this research program will help ensure that future industrial development in heavy crude upgrading and natural gas liquid processing will be conducted in an environmentally sound manner and that appropriate cost-effective treatment technologies are available to remediate any impacts of past practices.

Hydrogeological Aspects of Bitumen Heavy Oil Recovery

Heavy oil and bitumen resources are a viable alternative to conventional crude sources. Deep injection is a standard practice for the disposal of liquid wastes resulting from heavy oil extraction, but there is a significant lack of information as to the hydrogeological effects of this practice.

It is important that both industry and regulatory agencies to have access to knowledge indicating what data should be collected in advance of future deep injection developments, so as to assess their impacts accurately. Ultimately, in order to conduct the sustainable development of heavy oil deposits, it is critical that a method be found for the safe disposal of liquid wastes.

This PERD project focuses on developing guidelines for deep well disposal of *in-situ* waste water. In 1990-91, a study was designed to investigate deep injection, on the basis of recommendations from INTERA Technologies (1987). Because the experimental Shaft and Tunnel method of extracting bitumen from the McMurray Tarsands was very successful, the Underground Test Facility will be expanded to a pilot scale. Consequently, a new injection well is planned for the facility, with an expected active life span of 2 years. The research team, comprised of Environment Canada and the Alberta Research Council, will have access to this well for data collection. In another related project, Environment Canada and the Alberta Oil Sand Technology and Research Authority (AOSTRA) have teamed up to drill and instrument an observation well, approximately 10 km to the northeast of the Underground Test Facility, in order to monitor changes in the groundwater regime, due to extraction of bitumen from the McMurray Formation. The observation well will also be used to monitor changes in the Wabiskaw and adjacent formations due to injection. In future stages, the data will be used as the foundation for computer modelling, and ultimately, for the development of regulations and guidelines concerning deep injection.

Treatment of Aqueous Effluents From In-Situ Operations

Environmental research on issues related to synthetic oil production is proceeding in several areas.

At the present time, a number of *in-situ* technologies such as steam injection, are under investigation to recover heavy oil from deep underground deposits. The most promising technique uses steam injection and produces large quantities of water, along with the oil recovered. Recycling this water to produce steam would minimize the environmental impact of the *in-situ* heavy oil recovery process.

Membrane technology appears to be a promising alternative for treating the produced water to remove oil, suspended solids, and organic and inorganic contaminants. However, it is a new technology that requires considerable R&D efforts at the bench, pilot and semi-commercial level to demonstrate its cost-effectiveness.

The Wastewater Technology Centre has been conducting such studies with the support of PERD funding. Field experimental work on oil and suspended solids removal in 1989-90 identified a need for a long-term field testing of ultra-filtration and micro-filtration membranes at the bench scale, followed by long-term pilot evaluation of the most effective

membranes. This work commenced in 1990-91. In addition, pilot scale electrodialysis work, a vital component of membrane technology for total dissolved solids removal, is being conducted under a joint AOSTRA/oil industry/Environment Canada study. This will be followed by technology transfer to industry in 1992-93 and 1993-94.

Treatment and Disposal Practices for Sludges from Heavy Oil Recovery Operations

The continuing search for economically viable means of recovering Alberta and Saskatchewan heavy oils has led to the development of several thermal and chemical *in-situ* techniques for heavy oil recovery. These enhanced oil recovery techniques result in the generation of large volumes of waste oils, drill cuttings and oily sludges.

With a dramatic increase in the volume of heavy oil production waste sludges over the past two years, a more environmentally acceptable, yet practical means must be found to treat and dispose of these oily wastes to prevent serious environmental impacts and impediments to resource development. During 1990, a Phase I study was completed by Monenco Ltd. of Calgary which identified a short list of technology options with a strong potential for treating heavy oil-produced sand waste. In late 1991, a laboratory and greenhouse study was initiated to examine the effectiveness of surface bioreactor technology in pre-treating the high asphaltene content in oil wastes.

Success in this project will directly benefit oil companies requiring an acceptable disposal practice for heavy oil solid waste. It will also assist provincial and federal governments in the development of guidelines or codes of good practice for management of the wastes from heavy oil production. The project supports the concept of sustainable development, in that surface bioreactor technology may become the preferred pre-treatment process step for high volume and low toxicity heavy oil waste sludge and solids. Such a process is currently not available. Pre-treatment will reduce the level of environmental hazard posed by the waste to a point where the treated material can be safely disposed of either by land-filling or land treatment.

Characterization and Treatment Technologies for Effluents Generated from Shipping of Heavy Oil as a Water Emulsion

The purpose of this PERD project was to work, in conjunction with the oil industry, in the characterization of wastewater generated from the shipment of heavy oil as an emulsion and in the development of treatment technologies to manage this wastewater in an environmentally acceptable fashion.

However, in 1990-91, the oil industry reviewed its priorities in heavy oil emulsion shipping activities and indicated that their research in this area would be postponed.

Aquatic Assessment Protocols for Oil Sands Operations

As the Athabasca oil sands assume more importance in providing Canada's oil supply, it is necessary to understand the impact of bitumen operations on the aquatic environment. A demonstration of the impacts on water quality associated with the ongoing facilities, will be useful in judging the sustainability of further bitumen development and its comparative impact of bitumen relative to other upstream developments.

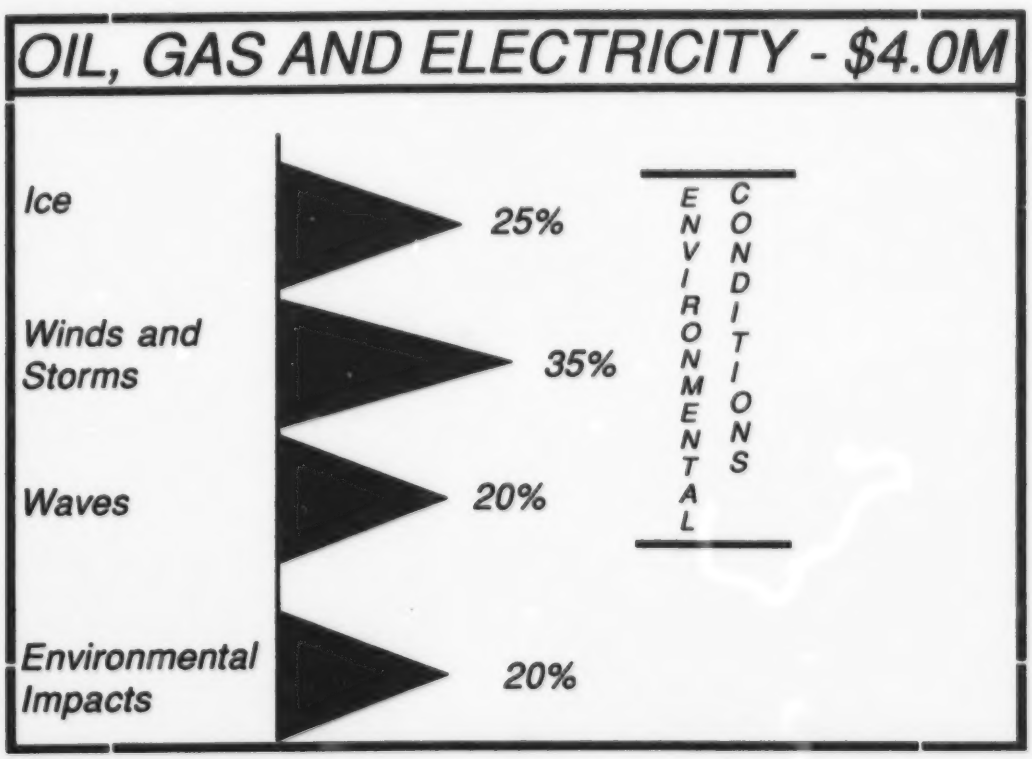
The process waters from the bitumen plants contain various compounds, which may be released into receiving waters as a result of plant upsets, licensed discharges, or release of treated tailings pond wastewater. This ongoing PERD project aims to develop the tools required for the assessment of the environmental impacts of bitumen development. The research focuses on identifying chemicals which may contaminate aquatic environments during mining and upgrading operations; determining their persistence, pathways and effects; and generating predictive models for use in impact assessment.

The National Water Research Institute has completed a broad-based field program on the lower Athabasca River during 1990-91 and 1991-92. Collections include water, and suspended and bed sediments from mainstem tributary inflows, and point sources from the Athabasca town site down to the Athabasca delta. Fish have been collected from selected mainstem sites on two occasions. Multi-parameter chemical scans and a battery of ecotoxicological tests are being applied to the samples collected. The results will be used for model development and for determining the relative contribution of industrial sources and background (natural) sources. If warranted, the model will be calibrated for a selected list of important contaminants in a future intensive sampling.

TASK 6: OIL, GAS AND ELECTRICITY

The conventional oil, gas and electricity sectors are vital elements in ensuring Canada's future energy security. Work, conducted under Task 6, provides the technical base for enhancing the economic potential of these sectors, particularly in relation to the supply of light-medium crude oil and gas from the frontiers, and for participation with utilities in developing electrical technologies.

The harsh and remote nature of the frontier environments means that careful attention has to be paid to the safety of human life and the protection of the environment. Environment Canada's portion of the Task, which is coordinated jointly by Environment Canada and Fisheries and Oceans Canada, relates to the improved forecasting of sea, ice and weather conditions and the management of the environmental impacts of hydrocarbon exploration and developments, principally in the Canadian frontiers.



MARINE ENGINEERING - DESIGN CRITERIA

Combined Environmental Extremes

Loads on offshore structures caused by such extreme environmental conditions as waves, winds, current, ice and icing are generally considered in combination, by simply adding the individual load values. The Royal Commission on the Ocean Ranger Marine Disaster noted that this frequently leads to over-design. Improved methodologies are required for realistic calculations of loads to form the basis of the new CSA S471 standard.

AES is uniquely well-placed to develop and test these methodologies, based on its software systems for data processing and its considerable body of scientific expertise. In conjunction with the Centre for Frontier Engineering Research in Edmonton, Alberta, this PERD project seeks to develop and implement methods for estimating the occurrence of combined extreme environmental events. During the 1990-91 project year, a prototype software system was developed, which will be used for estimating combined, extreme event probability. The final software system, to be implemented in 1992-93, will be, primarily, a micro-computer based system with interfaces to large databases of environmental information in Atmospheric Environment Service and Bedford Institute of Oceanography.

Evaluation of Climatologies

Over the years, a number of climatological descriptions of Canada's offshore drilling areas have been produced, based on a variety of data and analysis techniques. This proliferation of studies has caused considerable confusion. For example, the Hibernia Environmental Impact Statements (EIS) showed 5 different values for the 100-year wind and wave, with no effort to distinguish the "best" estimate, or even to illustrate the differences in their derivation.

The goal of this three year PERD study is to compile a comprehensive listing of climatological studies related to design and planning for offshore activities, with detailed descriptions of the methodologies, assumptions and data bases. This will be the basis for an evaluation of the studies identified and for efforts to determine the most appropriate values for significant environmental parameters. In 1990-91, a draft final report was prepared by the contractor, Seaconsult Marine Research Ltd. of Vancouver, containing a comparative evaluation of databases, analysis techniques and the assumptions and limitations of existing climatological studies. It is anticipated that the recommendations resulting from this project on the most appropriate values for important environmental parameters will be useful to offshore operators in meeting regulatory requirements such as Environmental Impact Statements, as well as to design engineers.

Wave Turbulence Interaction

Much of ocean wave theory is built upon the assumption that the ocean surface is made up of a field of random waves, each propagating independently according to the laws of linear theory. Increasingly, however, as more accurate prediction models are required, attention has been focused on the understanding of phenomena - such as wave group propagation - which are inherently non-linear.

This PERD project, conducted at the National Water Research Institute in Burlington, Ontario has employed a fully non-linear method, based on Fenton's Fournier wave theory, to study the evolution of wave groups in a wave tank. During 1990-91, studies were conducted to measure the velocity field beneath breaking waves; to determine the vertical distribution of turbulent energy due to wave breaking and wind stress; and to explore the effects of wave turbulence interaction on wave dissipation and mixing in the near surface layer. In addition, two papers on the numerical simulation of the propagation of non-linear groups were published.

Statistics of Shoaling Waves

The hydrodynamics of deep water wave breaking (white capping) and the accurate prediction of wave-induced velocities are very relevant to the development of Canada's conventional offshore energy resources. Improved knowledge in these areas should lead to enhanced engineering design, operational efficiency, safety and environmental protection in offshore drilling activities.

In 1990-91, this project concentrated on developing a theoretical model to obtain the joint probability distribution of wave heights and periods for shoaling waves. A subsequent step involved testing the model, using the data obtained from laboratory and field experiments. The deliverables included a paper on a theoretically consistent method for computing the velocity field beneath wave groups and the preparation of reports dealing with the joint distribution of wave height and period during shoaling.

Hindcasts and Satellite-Sensed Winds and the West Coast Wave Project

The accurate description of historical wind and wave fields is a critical requirement for many engineering design and operational requirements. In the absence of ice, waves are the most significant environmental load on offshore structures and vessels. Wave hindcasting has provided the most useful method of estimating design waves for engineering applications, but there have been difficulties in obtaining representative data to ensure accurate modelling. Two PERD projects address this issue: The first: Hindcasts and Satellite-Sensed Winds has the overall objective of developing new methodologies for the specification of historical marine wind fields, particularly using satellite data. Success in this project would mean that the computerized kinematic analysis developed through it, could be incorporated into regional forecast programs and large hindcast studies, where the cost of manual analysis is prohibitive. Ultimately, the improved forecasting ability would be of assistance to offshore operators in meeting regulatory requirements and to design engineers. In 1990-91 work was conducted to develop a prototype computerized kinematic analysis procedure for marine winds. This will form the basis for the further development of prototype hindcast techniques using satellite data in a later phase of the project.

The objective of the second PERD project: West Coast Waves is to produce extreme wind/wave hindcasts for the west coast of Canada. The intention is eventually to produce twice-daily hindcasts, over a three year period, fully verified with observed data for a normal wind and wave climatology. In addition, extreme hindcasts will be produced for approximately fifty storms in the Queen Charlotte Sound/Dixon Entrance area, for an extreme wind and wave climatology.

During 1990-91, work focused on the extreme wind/wave climatology section of the project. Complete deep-water, offshore wave hindcasts were produced for the top-rated 50 most severe wave-producing storms. This section of the project will be completed in 1992-93. No PERD-funded activity is planned until 1995-96 with respect to the normal wind wave climatology. In the interim, the wave database will be accumulating and the meso-scale capability will be developed under the new integrated hindcast project. A full-scale evaluation of the normal climatology, produced from the operational program, will be conducted in 1995-96.

Climate Change and Arctic Offshore Energy Development

In 1990-91, PERD funded an exploratory study to investigate the potential implications of global climate warming and sea ice thinning in the Beaufort Sea. This area has huge proven oil and gas reserves, which will require major capital investments over the next thirty to fifty years to develop. Clearly, any large-scale changes in climate could have major implications for offshore oil and gas developments in the area.

The study, which constructed scenarios of possible climates to investigate changes in the near shore ice regime, was undertaken by the MEP Company of Markham, Ontario and CANATEC Consultants Ltd. of Calgary, Alberta. The study indicated that the length of the open water season can be expected to increase from the current 40 to 90 days, to from 60 to 150 days under a warmer regional climate, while the maximum extent of open water can be expected to increase from the current 100 to 200 km offshore to 500-700 km, with a significant increase in wave heights. The maximum winter near shore sea ice thickness is expected to decrease by 50%.The frequency of intrusions of multi-year ice and ice islands during the open water season is expected to decrease considerably.

Further work will be conducted in future years on climatic factors which are important for engineering design. Since the cost implications of climate warming could be very significant for offshore developments in the Arctic, the final results of this PERD study are likely to be carefully studied by government and industry.

Ice and Ice Structure Interaction

The following three PERD projects will contribute to improving Environment Canada's technical capacity to assess ice-related environmental impacts. This is a key element in designing and planning the safe development of offshore energy resources. The results of these projects will be of assistance to governments in regulating offshore energy development. They will also assist design engineers and provide spin-off benefits in the form of the forecasting of spray icing and the improvement of technologies for reliable detection of structural icing in harsh environments.

Sea Ice Distribution

The purpose of this study is to develop a sea ice information system for Canadian waters. In support of this objective, the study has considered changes in atmospheric circulation during heavy and light ice winters, based on thirty six years of ice cover data; in addition, the study has looked at three regions of high sea ice and atmospheric variability.

The results of the study of the three regions suggested that changes in atmospheric circulation were consistent with the changes in storm tracks and meridional heat transport found in other studies. In particular in the Bering Sea, heavy ice winters were accompanied by the westward displacement of the main Aleutian Low and the formation of a secondary Low in the Gulf of Alaska, resulting in increased cold air advection over the north Bering Sea. For the Davis Strait/Labrador Sea, heavy ice winters were accompanied by intensification of the Icelandic Low, producing cold air advection over the area. For the Greenland Sea area, no statistically significant difference was found. It is thought that this may be due to the important role that ocean currents play in determining ice extent in this region.

Marine Icing

The principal objective of this project, scheduled for completion in 1992, is to develop ice accretion models for estimating design loads from freezing spray for vessels and offshore structures. A platform icing model, RIGICE, was developed in 1987, and a ship icing model, SHIPICE, was obtained from the University of Alberta in 1989. A joint model-evaluation project with the Norwegians, completed in 1989, revealed that both rig icing models over-predicted ice loads for typical east coast icing conditions. This over-prediction was considered to be related to large uncertainties in estimating the spray flux impinging on offshore structures, and in the case of RIGICE, to the fact that time-dependent splashing effects were not taken into account.

These two major sources of uncertainty were addressed in 1990 and 1991 through a series of controlled wind tunnel experiments on the spray icing process and wave tank experiments on the splashing process on vertical cylinders. These experimental results are being used to develop an enhanced version of RIGICE, which will be used to estimate design information (icing rate, ice load, maximum height of accreted ice) for the Scotian Shelf and Grand Banks. A final report, summarizing the model development R&D process and the results of applying the icing models, will be completed by the fall of 1992.

Ice Digitization Technology Development

The reliable statistics needed to support offshore engineering design and regulatory functions require a long-term, consistent and homogenous digital ice data base. Historically, this type of digital data has been extracted manually, but this method has severe limitations. This PERD project seeks to upgrade the digitized system and methodology.

As part of a joint project with the Earth Observation Laboratory of the University of Waterloo, the Sea Ice Chart Archiving (SICAR) system was developed during the period 1989-91. Future phases of the project will upgrade the SICAR system to improve its functionality and performance. It is planned to digitize the existing backlog of composite ice charts using SICAR. Subsequently, the system will produce digital ice charts in a format compatible with the Climatological Ice Data Archiving System (CIDAS) and possibly a PC-based GIS system.

ENVIRONMENTAL FORECASTING

Satellite Radar Studies

Currently, the Ice Centre receives ice information from a variety of sources, such as weather satellites, LANDSAT, ice reconnaissance aircraft and ships. In 1991, ERS was launched and will be followed by RADARSAT in 1994. The volume of digital data generated by these satellites will be, at least, of an order of magnitude greater than anything currently received, and will have to be processed, analyzed and archived. It will supplement the data which became available after synthetic aperture radar (SAR) and side-looking airborne radar became the operational sensors for conventional aircraft reconnaissance.

This PERD project seeks to prepare the Ice Centre for the introduction of satellite radar data, by recommending and implementing the equipment and procedural techniques that will be required to process this data into ice information products for users. During 1990-91, development began on the specifications for the upgrade of the baseline Ice Data Integration and Analysis System (IDIAS) to full RADARSAT capability. Detailed studies of ERS-1 and RADARSAT orbits were completed to estimate the amount of ice reconnaissance aircraft time that might be saved by using satellite SAR data in place of aircraft. In addition, equipment, that will be required in future phases of the project, was acquired.

Canadian Atlantic Storms Program (CASP) II

The long-term goal of the Canadian Atlantic Storms Project (CASP) is to improve the prediction of the meso-scale structure of Canadian East Coast winter storms, as well as the storms themselves. As a result of the first CASP field project in 1986, conceptual models of the storms have been formulated; considerable progress has been made in modelling storm evolution; and improvements have been achieved in the use of instruments. In addition, a special forecasting centre was operated during the field phase, which provided the researchers with a greater appreciation of the requirements of future meso-scale forecasting.

The project has now moved on to CASP II, which will be focusing on the meso-scale structure of storms affecting the Avalon Peninsula/Hibernia region, with the field experiments scheduled for January to March 1992. Sea ice is a major concern of CASP II, since the behaviour of ice poses serious problems in offshore activities, while storms play an important role in ice movements.

The effect of the coastline in determining storm features along the jagged Avalon Peninsula is likely to be far more complex than was the case for the almost linear southern Nova Scotian coastline. This second phase of the CASP project promises to result in an improved understanding of the interaction between the atmosphere, sea ice and ocean.

Oil Mixing by Breaking Waves

In the open ocean, oil is naturally mixed by breaking waves. Recent advances, previously funded by PERD, suggest that it is possible to achieve surface characterization of the breaking wave, sensed remotely and analyzed in real-time. The next step would be to develop a fractal model of oil breakup on a wind-driven sea. This would be of great assistance with an Arctic spill, where an immediate estimate of the horizontal percolation through the rough underside of the ice cover would be necessary.

During 1990-91, in cooperation with the contractor, Sea Scan, a model of oil mixing as a Bescovitch-Cantor process controlled by a single parameter (equivalent to the Beaufort Sea state), has been developed. In addition, a laboratory study of entrainment by a breaking wave, and a fractal singularity strength evolution was conducted. The original PERD project "Oil Mixing in Wind Waves" is scheduled to be completed in 1992, with work continuing in the new area of fractal classification of geophysical images, oil spill dispersion and the supporting laboratory work on individual breaking waves.

Marine Wind Forecasting

Recent experiments have suggested that wind forecasting is the weakest link in the successful modelling and forecasting of most marine environmental parameters, including ocean waves, freezing spray and oil spills. Work on wind forecasting techniques has proceeded on several fronts, but these experiments aim for the general improvement of forecasts and are not specifically targeted on the need for marine forecasts and environmental models. The objective of this ongoing PERD project is to develop improved marine surface wind forecast techniques for use by AES and the private sector. The results of this research will also be used to improve the delivery of environmental prediction services.

It was hoped that a new improved wind forecast model would be completed in 1990-91 for use in the Canadian Spectral Ocean Wave Model. However, as a result of expert staff leaving the contractor, there has been a delay of approximately two years in the project. Since actual verification data is urgently required to support environmental modelling projects, the overall project has been rescoped. The effort will now concentrate on conducting one high quality verification experiment with current data and new data sources that can be tapped in 1992-93. Objective marine wind forecast procedures will also be developed using the best data currently available.

Ocean Wave Modelling

The overall objective of this PERD project is to develop and bring into operation a modern, spectral ocean wave forecasting model. At present, the only operational ocean wave forecasting model in use in Canada is the parametric model based on the Bretschneider nomogram. Comparison experiments recently conducted have shown that it is possible to produce superior wave forecasts using spectral models. There are several such models of varying degrees of sophistication available in research communities around the world. This PERD project is designed to support the acquisition of a research model, the adaptation of the model to operations and the conduct of the research necessary to make the model responsive to the unique problems of wave forecasting in Canadian waters (e.g. waves in the presence of sea ice).

Significant progress was made in 1990-91. The first version of the Canadian Spectral Ocean Wave Model went fully operational for the Atlantic in November 1990 and for the Pacific in January 1991. A Forecaster's Guide to the Canadian Spectral Ocean Wave Model was distributed in October 1991. The project was due to be completed by 1992. The upgraded version of the model will include advanced wave interaction processes which cannot now be run operationally due to time constraints. The implementation of the upgraded model is scheduled to facilitate incorporation of research from the Experiment on Rapidly Intensifying Cyclones over the Atlantic (ERICA) and possibly, CASP II.

Experiment on Rapidly Intensifying Cyclones Over the Atlantic (ERICA)

It is important to obtain improved storm forecasts for the Atlantic coast, as storm winds during the winter can increase in this region by over 50 miles per hour in just one day. To achieve this, a joint project, ERICA, is underway, involving the Canadian and U.S. governments, as well as scientists, technicians and engineers from the universities and private research organizations.

The Canadian portion of the work has been funded by PERD. During 1990-91, the objective was to analyze ERICA field phase data to gain a better understanding of rapid storm deepening. This information will, subsequently, be used in applied research to produce improved storm forecasting techniques. The next task is to identify the essential physics which must be taken into account to facilitate adequate forecasting, based on sound physical principles.

Operational Ice Modelling

In 1987, an operational ice modelling group was set up including representatives from Atmospheric Environment Service, Energy, Mines and Resources, Fisheries and Oceans Canada and Gulf Canada. Its mandate was to review the state of operational ice modelling, to identify relevant research and transfer the results to operations and, finally, to determine the priorities for the work to be accomplished under this PERD project. The working group recommended the development of standard methods and data sets for verifying ice model performance, so that benchmarks could be established against which current results and future improvements could be measured. Success in the project will be of assistance in ensuring safe and economic operations by government and the private sector on both the East Coast and in the Beaufort Sea.

During 1990-91, through contracts with Arctic Sciences Ltd. of Dartmouth, Nova Scotia, and F.G. Bercha and Associates of Calgary, Alberta, standard verification and data sets were developed for the East Coast and the Beaufort Sea. Norland Science and Engineering Ltd. of Ottawa assisted in project management and evaluation, while ice beacons were obtained from MetOcean Data Systems Ltd. of Dartmouth, Nova Scotia for ice drift studies. This work prepared the way for enhancement of the data set and an evaluation of the model in 1991-92. and subsequent work will be directed at correcting weaknesses in the model.

Sea Ice Tracking Algorithm

The PERD project on satellite radar studies is preparing the Ice Centre for the introduction of satellite radar data and establishing a facility to receive and process this radar data. The original view was that analysis of radar data would be a manual task and the techniques and procedures developed would support this task. However, one of the techniques investigated in the project was an algorithm to track sea ice features automatically in time sequential radar and kinematic information. This clearly offered qualities superior to manual analysis.

This PERD project was set up to undertake implementation and trial demonstration of this algorithm. Success in the project will result in kinematic information from SAR imagery being provided that would assist in the development of arctic oil and gas in all its phases, including the shipping of oil and gas to southern markets. During 1990-91, a survey of user requirements was conducted and documented by the contractor, Noetix Research Inc. of Ottawa. Subsequently, a functional specification for the Ice Tracking Software was developed along with the Ice Tracker User's Manual. In 1992, an operational demonstration was to be undertaken and, if successful, the Ice Motion Algorithm installed on an operational system at the Ice Centre for an extended demonstration using ERS-1 and aircraft SAR data. An operational demonstration using real-time ERS-1 and aircraft SAR data is scheduled for 1993-94.

ENVIRONMENTAL IMPACTS

Integrated Hydrocarbon Monitoring

Offshore exploration drilling for oil and gas has been taking place in Canada for over a decade and the production phase is imminent. Tanker traffic in Canadian waters is increasing. Past experience has shown that increased spillage of oil usually accompanies such increases in activity. If the environment is to be protected, it is essential that complete and timely information on oil spill position and extent be readily available to commanders of clean-up operations. Since 1987, Environment Canada, supported by PERD, Fisheries and Oceans Canada, Canada Centre for Remote Sensing, American Petroleum Industry (API), U.S. Minerals Management Service, and United States Coast Guard, has sponsored a program to develop and test instrumentation capable of mapping spilled oil, on water, shorelines and ice, and chlorophyll and other environmental variables in near surface waters. A prototype Laser Environmental Airborne Fluorosensor (LEAF) has been constructed and flight tested under controlled conditions. It has demonstrated reliable discrimination capability for crude oil on water, rocks, sands, gravel, and ice. Longer wave-length capacity is under development for the measurement of environmental variables that have useful application in oceanography.

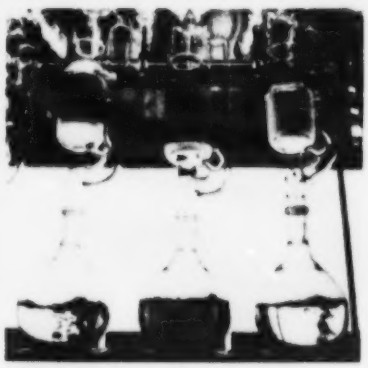
Organic Pollutants from Flare Stacks

Many industrial processes require safe and economical ways to dispose of waste and purge gases, or, to a lesser degree, of volatile liquids. The recovery and processing of fuels, such as natural gas, oil and coal result in significant waste streams, with the potential to release large quantities of pollutants into the environment. The most commonly-used method to reduce these emissions is by flaring the waste gases. However, the efficiency of the flare in combusting these gases is complex. Reliable methods for examining their emissions are not fully developed and little is known about the overall emissions they create.

The objective of this PERD project is to conduct laboratory flaring studies and commence construction of a pilot-scale, flare system. The research will lead to the development of adequate knowledge and technology bases required for the environmentally acceptable burning of gases. This, in turn, lead to the removal of a major obstacle to clean oil and gas production, by developing an environmentally acceptable technology for waste gas combustion. Although the main beneficiary of this technology will be the oil and gas industry, it will undoubtedly also be applicable to the chemical industry. This will assist provincial environment departments in the assessment and amendment of legislation dealing with the emission of pollutants by industry. The research will also help industry to optimize existing flaring practices.

Treatment of Wastewater from Offshore Oil Production

Production of oil from both onshore and offshore oil recovery operations generates substantial volumes of oilfield brines which must be handled in an environmentally sound manner. Removal of residual suspended oil is a critical step in the handling and treatment of these brines. Conventional treatment of oilfield brines for oil removal generally involves the use of unit processes, designed to separate the oil by gravity (or enhanced gravity) settling. The use of these processes is typical of both offshore and onshore oil production in all producing regions of the world. However, these processes are prone to serious operating difficulties, and as a result, alternative oil removal processes are required to treat the oilfield brines more effectively than is possible with conventional processes.



Under this PERD project, Wastewater Technology Centre in Burlington, Ontario has been evaluating such technologies and investigating improved methods for process control and discharge monitoring. The project has been generating significant interest from regulatory agencies in Canada and from the U.S. Environmental Protection Agency, as well as continued support from the oil industry.

During 1990-91, a number of publications were prepared; one of the technologies, the CSPI Vortoil static hydrocyclone, was tested under simulated Canadian offshore conditions; an agreement was reached with the Canadian Department of National Defense - Navy Fleet systems for testing oil content monitors; and five monitors were selected for initial evaluation.

Long-Term Fate and Persistence of Oil Stranded on Coarse Sediment Beaches

Coarse sediment shorelines, common on all three of Canada's coasts, present serious oilspill clean-up problems. Yet our understanding of the dynamics and oil/sediment interactions for this type of beach is inadequate. Quantitative data on stranded oil fate and persistence is also lacking. The purpose of this new PERD project is to improve the capability to predict oil fate and estimate natural self-cleaning rates of coarse sediment beaches. This will give government and industry the scientific information they require to make decisions related to shoreline clean-up and to predict and assess environmental impacts.

During 1990-91, the project collected and evaluated historic and contemporary data sets; assessed current models for estimating fate and persistence; proposed a conceptual model and identified the output requirements of a model which would describe the Canadian scenarios. Future stages of the project will continue - data acquisition and compilation, develop the model and algorithms, and identify and pursue information deficiencies through bench-scale investigations and monitoring.

Condensate Effects on Commercial Species

Dispersants have long been used to deal with petroleum and petroleum product spills into seawater. Past investigations of crude petroleum in respect of the impacts on marine life have focused on the toxicity and tainting effects of the water-soluble fractions which, over time, are subject to infinite dilution, but have ignored particulate oil normally present as droplets in oil/water mixtures. This new PERD project will fill this gap by investigating the short-term (24-hour) tainting potential of a North Sea and Corexit 9527 crudes, alone and in combination, using adult sea scallops. In addition, a standard analytical protocol for chemicals, both in water and in tissue, is required before an appropriate screening test for evaluating commercial fish catches can be developed.

As a first step, a steering committee including representatives from Fisheries and Oceans Canada, Environment Canada, Texaco and LASMO Resources Ltd. developed terms of reference for the 1990-91 studies. A contract was let with Seachem Oceanography of Sidney, B.C. to conduct an in-depth literature search related to petroleum tainting of marine organisms and to develop and test an appropriate analytical protocol. In addition, a second contract was let with the Canadian Institute of Fisheries of the Technical University of Nova Scotia. In this study, adult sea scallops were exposed to crude oil, dispersed crude oil and dispersant (Corexit 9527).

It is anticipated that the work conducted during 1990-91 will lead to a significant improvement in understanding the problems related to tainting and result in the development of standard methods needed for measuring taint.

Pollution from the Offshore Oil Industry: Putting it into Perspective

Experience in the North Sea and elsewhere indicates that controlled operational discharges by the offshore oil exploration and production industry need not be synonymous with extensive long-term ecological devastation. Public concern has led to the requirement for detailed assessments before drill permits are granted. However, little attention has been given to the impacts of discharges from fishing, marine transportation, disposal of industrial, domestic and human wastes and other traditionally accepted uses of the offshore area. Nor has there been much attention paid to alteration of habitat or to the removal of target species by the fishery. Yet these activities have had clearly demonstrable and significant effects on renewable resources and habitat. Consequently, there is a need to consider the potential impact of frontier oil exploration and production in terms of the existing impacts of other users. This should make it possible to derive a balanced perspective of the significance of the impact of potential pollution arising from the Canadian offshore and production, relative to the impact from other users of these areas.

This PERD project aims to fill the gap by examining estimates of pollution and the potential for the alteration of marine habitat by the development of the Hibernia oil field on the Grand Banks, the VENTURE gas and condensate field on the Scotian Shelf, and the undefined resource on Georges Bank and placing them in context with comparable estimates from other users of these areas, especially the fishing and shipping industries.

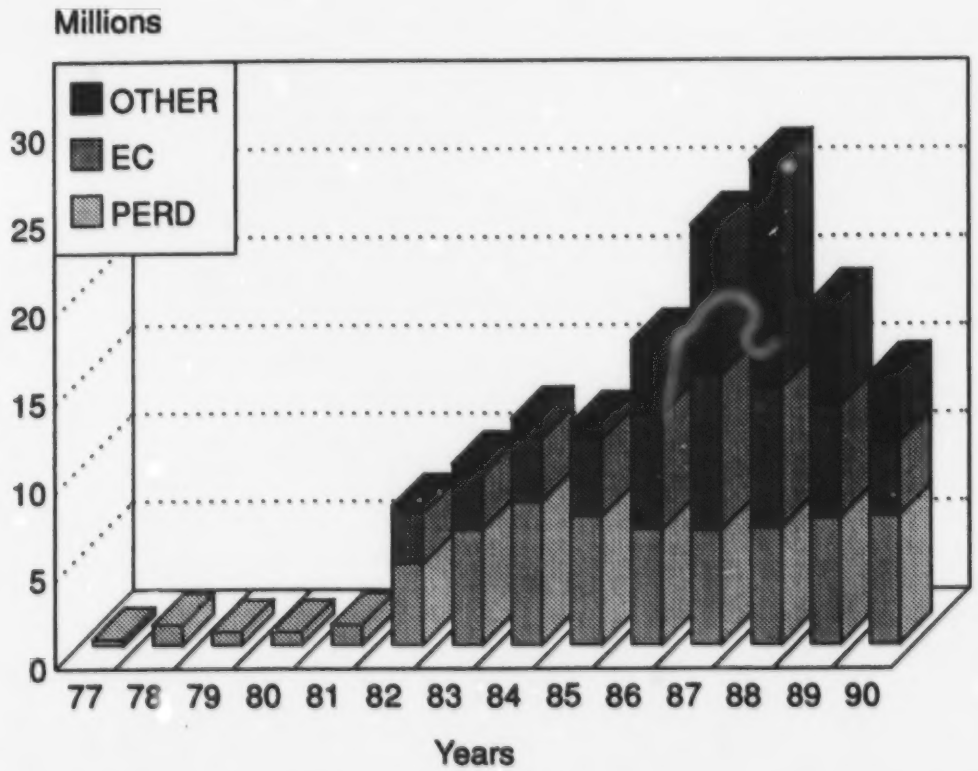
During 1990-91, a report was produced by the contractor, Wilkinson Research and Consulting, Halifax, summarizing the information available on the predicted inputs of oil from exploration on the Grand Banks and Scotian Shelf, as well as on the inputs of oil and other contaminants from other users of the offshore environment.

FINANCIAL PROFILE

In September 1991, the Government of Canada reconfirmed its commitment to the Federal Energy R&D Program. The decision authorized the Program to receive funding of $90 millions for a further 5 years commencing in 1992-93.

Environment Canada receives approximately 8% of the total funding from the Energy Research and Development Program. This funding source is authorized by the Panel on Energy Research and Development (PERD) and receives its R&D direction through a system of interdepartmental committees that incorporate industry recommendations. Over the years, Environment Canada has augmented the resources available through A-Base contributions and partnerships.

In 1990-91, Environment Canada received $7.2 million and 15 PYs from the federal PERD budget. The total source of funds, which includes the amount of partner funding, and in-kind contributions for the fiscal year 1990-91, reached $ 15.2 millions and 57 PYs. Most of Environment Canada's projects are funded jointly between PERD and one or more partners,

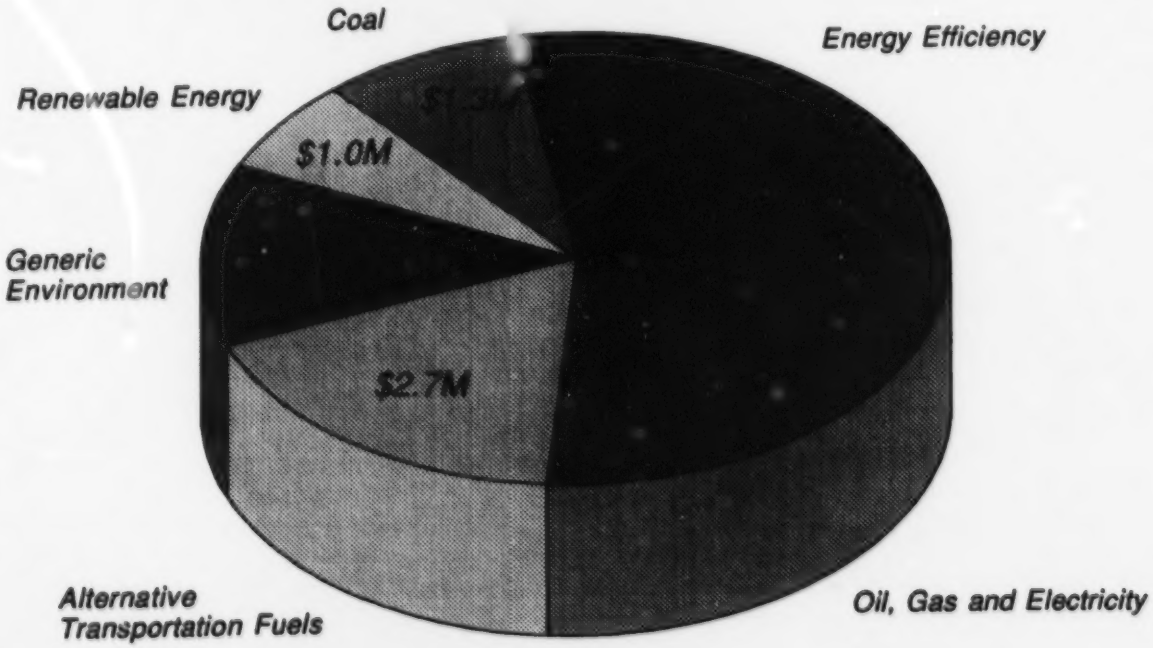


as shown in Table, including industry, other governments and university. The contribution from Environment Canada's A-Base and from partners amounted to $4.2 million and 52 PYs and $3.8 million respectively. Environment Canada contributes significantly to this program through the use of its expert scientists. This leverage of $1.08 for each PERD $1.00 represents a continuation of the interest in energy/environment R&D.

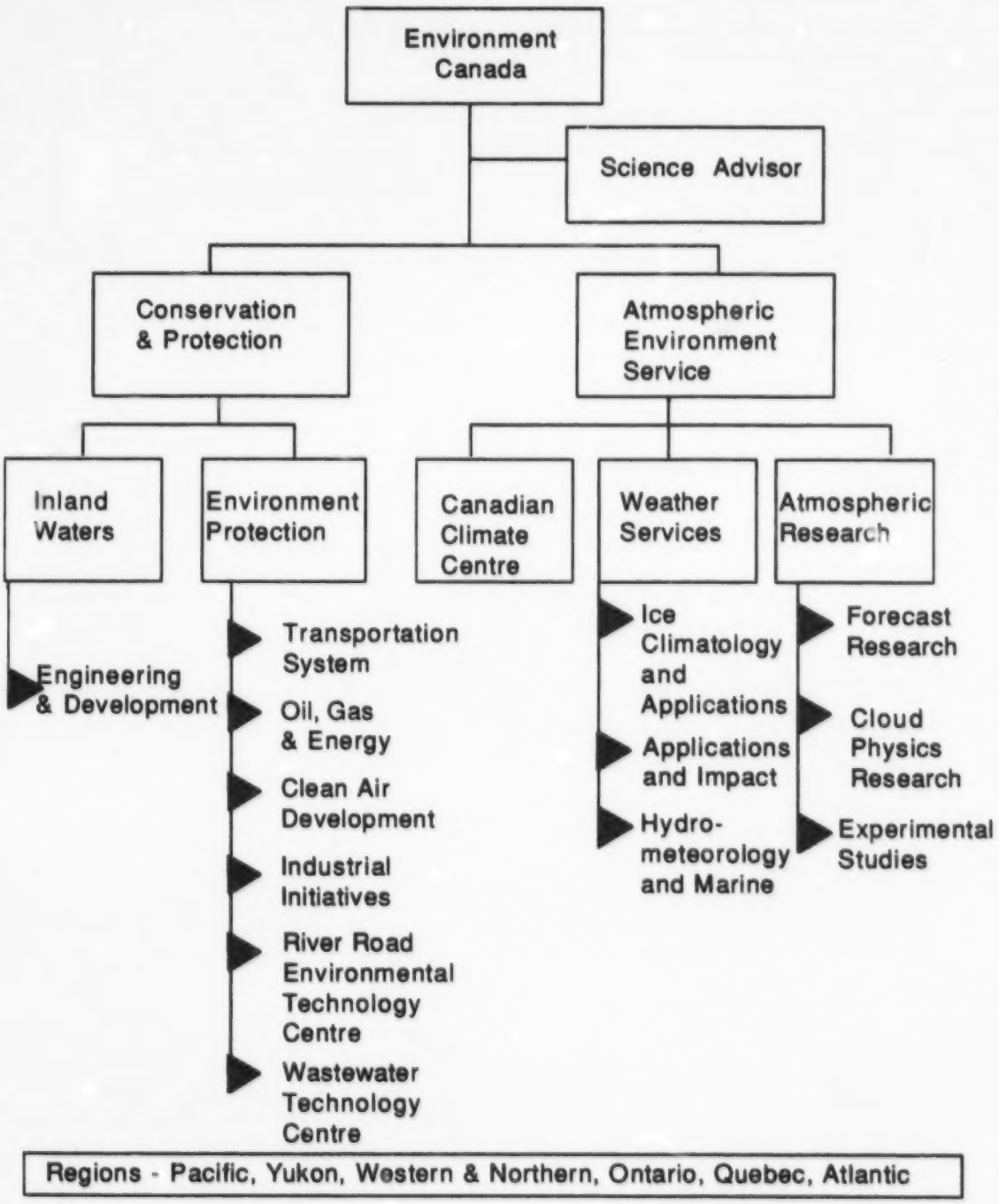
These partnerships remain critical in carrying-out Environment Canada's component of the Energy R&D Program. Some partners include:

▸ Industry Amoco Canada Petroleum Co. Ltd. Canadian Electrical Association Canadian Petroleum Association Canadian Petroleum Products Institute Canfor Ltd. Esso Fafond et Frères Murphy Oil Co. Ltd. Petroleum Association for Conservation of the Canadian Environment Pan Canadian Petroleum Ltd. Quinsam Coal SNC Research Corp. Westmin Resource Ltd. Zenon Environmental Services Inc. ▸ International Agencies: European Centre for Medium Range Forecasting International Energy Agency U.S. Environmental Protection Agency U.S. Mineral Management Service U.S. National Science Foundation U.S. Office of Naval Research	▸ Other Governments (Provincial/Municipal): Alberta Environment Alberta Oil Sands Technology and Research Authority Alberta Research Council British Columbia Ministry of the Environment Cape Breton Development Corporation Energy Resources Conservation Board Nova Scotia Department of the Environment Ontario Ministry of the Environment ▸ Federal Government: Agriculture Canada Committee on Atlantic Coal Defence Research Establishment Atlantic Department of National Defence Department of Supply and Services Energy, Mines and Resources Canada Fisheries and Oceans National Energy Board National Research Council

The resource distribution divided into Tasks is as follows:



ANNEX 1 - Organizational Structure



ANNEX 2 - Energy/Environment Specialist Roster

The following list highlights Environment Canada's specialists in energy/environment research and technology development. Specialists listed represent a small proportion of Environment Canada's scientists and engineers, conducting or managing research and technology development in energy related projects. This directory provides a quick reference guide to the Department's specialists with unique expertise in the area of energy and environment issues.

▸ ENERGY EFFICIENCY

Industrial Waste Recovery	George Hill	(819) 953-8718
Energy from Waste - NITEP	Abe Finkelstein	(819) 953-0226
- Pulp and Paper	Ed Wituschek	(604) 666-2815
Sludge Processing Systems - Optimization	Herb Campbell	(416) 336-4717

▸ COAL

Mining Wastewater Treatment	Brian Kelso	(604) 666-5193
Transportation (Dust)	David Poon	(604) 666-2862
Refuse Management	Roy Parker	(902) 426-8564
Combustion - Advanced Combustion/ Emissions Control	Kash Ram	(819) 953-2267
- Solid Waste Control	Geoff Ross	(819) 997-1222

▸ RENEWABLE ENERGY

Solar Energy	Robert Morris	(416) 739-4361
Wind Energy	J.L. Walmsley	(416) 739-4861
Small-Scale Hydro	Eon Park	(819) 997-2308
Bioenergy - Industrial Waste	A. Schnell	(416) 336-6427

▸ GENERIC ENVIRONMENT

Energy		
- Global Warming	Henry Hengeveld	(416) 739-4323
- Radiatively Active Gases (CO_2)	L.B.J. McArthur	(416) 739-4664
- Carbon Cycle Model	K. Higuchi	(416) 739-4452
Groundwater and Soil Remediation	Alex Lye	(416) 336-6438
Energy Technology Systems Analysis Program	John Hollins	(819) 994-5167

▸ ALTERNATIVE TRANSPORTATION FUELS

Oil from Sludge	Herb Campbell	(416) 336-4717
Fuel Use - Emissions	Chandra Prakash	(819) 997-1614
Pollution Abatement Technologies	Rick Scroggins	(819) 997-1223
Oil Sands and Heavy Oil - Deep Well Disposal of Waste	Barry Munson	(403) 468-8034
- Wastewater Recycling	Sandra Kok	(416) 336-6002
- Land Disposal of Sludge	Don Waite	(306) 780-6438
Heavy Oil Shipping - Wastewater	Abbas Zaidi	(416) 336-4618
Oil Sands - Aquatic Assessment	R. Bourbonniere	(416) 336-4547
- Tailings Pond Sludge	Barry Munson	(403) 468-8034
Synfuel Processes - Waste Technologies	Herb Campbell	(416) 336-4717

▸ OIL, GAS AND ELECTRICITY

Frontier		
- Combined Environmental Extremes and Climatologies	P. Louie	(416) 739-4347
- Atlantic Storms and Rapidly Intensifying Cyclones	Ronald Stewart	(416) 739-4608
- Wave Forces	M.A. Donelan	(416) 336-4879
- Oil Mixing by Waves	B. Kerman	(416) 336-4798
- Hindcast Winds/Waves	P. Louie	(416) 739-4347
- Wind Forecasting and Modelling	Alan Bealby	(416) 739-4908
- Climate Change Impact (Arctic) and Sea Ice	B. Maxwell	(416) 739-4385
- Sea Ice (Satellite)	John Falkingham	(613) 996-4552
- Icing on Offshore Structures	Ross Brown	(613) 996-4488
- Ice Digitization	Dave Mudry	(613) 996-4214
- Ice Data Integration and Analysis System (IDIAS)	Don Champ	(416) 739-5088
- Ice Modelling	Tom Carrieres	(613) 996-4674
- Hydrocarbon Monitoring and Fish Tainting	Roger Percy	(902) 426-2576
- Oily Brine Wastewater	Karen Simms	(416) 336-6003
Western Basin - Flare Stacks	Vinod Marwaha	(403) 468-8030

▸ PROGRAM COORDINATION

Panel Member	A.J. Chisholm	(819) 953-9607
Departmental Coordination	Duncan Hardie	(819) 953-7625
Conservation and Protection	Alka Steenkamer	(819) 953-8064
Atmospheric Environment Service	Ralph Horne	(613) 996-4248

ANNEX 3 - Conferences, Workshops, Seminars and Courses

Throughout the year, a number of events are organized and co-sponsored by Environment Canada's Energy R&D Program on a variety of energy/environment R&D topics. Workshops, conferences, seminars and even courses enable the department to transfer its new knowledge and technologies to industry, universities and government. These events also encourage a direct exchange of information on the future direction of R&D to meet a diversified, sustainable energy program.

Conferences ▸ Workshops ▸ Seminars ▸ Courses	Date ▸ Location
1st Annual Groundwater and Soil Remediation R, D&D Symposium	January 30-31, 1991 Ottawa, Ontario
Advanced Oxidation Processes for the Treatment of Contaminated Water and Air.	June 4-5, 1990 Toronto, Ontario
Course & Seminar on Selective Reduction for Control of Nitrogen Oxides Emissions from Boilers and Incinerators	March 4-6, 1991 Ottawa, Ontario
Energy Technology Systems Analysis Project - Scoping Meeting for a Canadian Reference Group	March 18, 1991 Ottawa, Ontario
Energy Technology Systems Analysis Project - Annex 4 - Brookhaven National Laboratories - Fall Meeting	November 18-22, 1991 Upton, New York
Energy Technology Systems Analysis Project - Annex 4 - June-Spring Meeting with IIASA	May 21-24, 1991 Laxenburg, Austria
Evaluation of Integrated Coal Gasification Combined Cycle for Canadian Utility Applications.	March 29-30, 1991 Montreal, Quebec
First International Symposium on Oil and Gas Exploration Waste Management Practices	September 10-13, 1990 Louisiana, U.S.A.
Global Change: Energy Alternatives, Environmental Consequences and Northern Implications	April 26-28, 1990 Whitehorse, N.W.T.
Meeting on Coal R&D	March 25-27, 1991 Calgary, Alberta
Prevention and Treatment of Soil and Groundwater Contamination in the Petroleum Refining and Distribution Industry	October 16-17, 1990 Montreal, Quebec
Technical Meeting on Natural Sources and Sinks of Greenhouse Gases	February 5-7, 1991 Downsview, Ontario

ANNEX 4 - Technical Reports and Conference Papers

Development and Demonstration of Resource & Energy Conservation Technology Program (12201)

Environment Canada, (in press). *Canadian Pacific Forest Products Ltd.: Dewatering Pulp and Paper Mill Sludge Using the Kamyn Ring Press.*

Environment Canada, (1990). Presentation made at the International Conference on Pollution Prevention: Clean Technologies/Clean Products, Washington, D.C.

Environment Canada, (1990). Presentation made at the Ontario Waste Management Association: Annual Meeting, Toronto.

Environment Canada, (1990-91). *Resilog.* Six issues of the newsletter published.

Environment Canada, (1991). *Development and Demonstration of Resource and Energy Conservation Technology 1988-91.*

Environment Canada, (in press). *Canadian Chemical Reclaiming Ltd.: Construction and Demonstration of a Portable Chemical Processing Unit for Purifying Recovering Waste Gas Treating Chemicals from the Petroleum Industry.*

Environment Canada, (in press). *Centre de Tri Gaudreau Inc.: Demonstration of a Model Recycling Facility for a Medium-Sized Municipality.*

Environment Canada, (1990). *Thermonic Inc.: Recovery of Chromium from Plating Shop Wastewaters.* (EPS 3/SF/1).

Environment Canada, (1990). *Circtronics Inc.: Technical and Economic Viability of a Copper Recovery/Waste Management System for the Printed Circuit Board Manufacturing Industry.* (Unpublished Report).

Environment Canada, (in press). *Lafarge Canada Inc.: Utilization of Industrial Wastes as an Alternative Fuel Source in a Cement Kiln.*

Environment Canada, (in press). *Forsetic Inc.: Development and Demonstration of the Selective Pumping Process in the Collection and Disposal of Septage in Rural Areas.*

Environment Canada, (1991). *Agrinove Dairy: Recovery of Proteins and Fats Lost in the Dairy Industry.* (EPS 3/FP/2).

National Incinerator Testing and Evaluation Program (NITEP) (12203)

Alliance Technologies Corporation, (1991). *The Environmental Characterization of RDF Combustion Technology: Vol. IV - Project Data and Results.* Environment Canada Publication WM-14, book #3.

Alliance Technologies Corporation, (1991). *The Environmental Characterization of RDF Combustion Technology: Vol. III - Sampling and Analytical Procedures.* Environment Canada Publication WM-14.

Chandler, J., (1991). *An International Perspective on Ash from Municipal Waste Incinerators.* Presented at the Municipal Waste Combustion Second International Conference, Tampa, USA, AWMA, pp. 87-94.

Chandler, J., (1991). *Progress of an International Approach to Municipal Waste Combustion Ash.* Presented at WASCON'91, Maastricht, the Netherlands.

Environment Canada, (1990). *NITEP Update "Final Edition", The National Incinerator Testing and Evaluation Program Newsletter.* 4 pp.

Finkelstein, A., (1991). *An Overview of Environment Canada's National Testing and Evaluation Program (NITEP).* Presented at the Municipal Waste Combustion Second International Conference, Tampa, USA, AWMA, pp. 1-16.

Finkelstein, A., (1991). *The Rational for Canada's Operating and Emission Guidelines for Municipal Solid Waste Incinerators.* Presented at the AWMA 84th Annual Meeting, Vancouver, B.C.

Hartmann, M., (1991). *An Overview of the Fate of Metals during Combustion at the Mid-Connecticut Resource Facility.* Presented at the Municipal Combustion Second International Conference, Tampa, USA, AWMA, pp. 347-362.

Hay, D., (1991). *International Address: Incineration - Examining the Issues.* Presented at the New Directions in Waste Management and Technologies, Sydney, Australia.

Kilgroe, J., (1991). *The Joint EC/EPA Mid-Connecticut Test Program: A Summary.* Presented at the Municipal Waste Combustion Second International Conference, Tampa, USA, AWMA, pp. 312.

Kosson, D., (1991). *Residue Leaching and Management Issues: An International Perspective.* Presented at the Municipal Waste Combustion Second International Conference, Tampa, USA, AWMA, pp. 95.

Sawell, S.E., T.W. Constable and R.K. Klicius (1990). *The National Incinerator Testing and Evaluation Program: Characterization of Residues from a State-of-the-Art Mass Burning Municipal Waste Incinerator (Burnaby, B.C.).* Environment Canada Publication IP-110.

Sawell, S.E. and T. W. Constable, (1990). *The National Incinerator Testing and Evaluation Program: Characterization of Residues from a Two-Stage Incinerator with Rotery Kiln (3M Canada).* Environment Canada Publication IP-119.

Sawell, S.E. and T.W. Constable, (1991). *Evaluation of Solidified Fabric Filter Ash from a Mass Burning Municipal Waste Incinerator with Lime-Based Air Pollution Control (Burnaby).* Environment Canada Publication WM-15.

The National Incinerator Testing and Evaluation Program. Environment Canada ISBN 0-662-58053-2.

Energy Conservation Through the Optimization of Sludge Processing Systems (12204/5)

XCG Consultants Ltd. and W.W. Schuk Inc., (1991). *A Status Report on Instrumentation and Control Capabilities in Sludge Treatment Processes.*

Environmental Protection Criteria - Coal Mining and Processing (22102)

Norecol Environmental Consultants, (1991). *Evaluation of Wetlands For Nutrient Removal From Coal Mine Wastewater: Pilot Scale Annual Report - Year 2, Report #2.*

Coarse Coal Refuse Management (22103)

Jacques, Whitford and Associates Ltd., (1991). *Physical and Chemical Analyses of Samples of Coarse Rock Waste, Cape Breton Development Corporation, Victoria Junction, N.S.*

Khan, D., (1991). *Victoria Junction Coal Preparation Plant Coarse Waste Rock Disposal Study - Project Outline for Test Dump Construction.*

Management of By-Products from Fluidized Bed Combustion (FBC) of Coal, and Other Technologies for Control of Combustion Emissions from Stationary Sources (22104)

Alberta Oil Sands Technology and Research Authority (AOSTRA), (1991). *Carbon Dioxide Disposal Study - Phase I Report, Vol. 1 and Appendix, Vol. 2.* Prepared by consortium including Environment Canada.

Becker, E. R., (1991). *Selective Catalytic Reduction of Nitrogen Oxides - Catalysts Reactors Processes.* Course notes prepared for Environment Canada and the Canadian Electrical Association.

Dearborn Environmental Consulting Group, (1991). *Variability of Circulating Fluidized Bed Combustion Ash Characteristics for Disposal, Part I -Coal and Part II - Petroleum Coke.*

Environment Canada, (in press). *Interim Recommended Practices for CFBC Residue Management.* EPS report.

Koppang, R. and G. Taylor, (1991). *SCR Mini Pilot Plant Preliminary Design Report.* Prepared for the Canadian Electrical Association and Environment Canada.

Lipinsky, E.S., (1991). *R&D Status on Carbon Dioxide Separation, Disposal, and Utilization Technologies.* Prepared for a consortium including Environment Canada and headed by TransAlta Utilities Corp.

Monenco Consulting Ltd., (1991). *Review of AECL Selective Catalytic Reduction Patented Process to Reduce NO_x Emissions with Hydrogen over Hydrophobic Catalysts.*

Padgett Process Services Ltd., and RTM Engineering Ltd., (1990). *A Study to Assess the Available Technology and Associated Costs of Reducing NO_x Emissions.* Report prepared for a consortium including Environment Canada and led by PACE.

Preto, F. and E.J. Anthony, (1991). *Assessment of Nitrous Oxide Formation in Power Plant Plumes - Phase I.* Prepared for CANMET and Environment Canada.

Advanced Coal Combustion Emissions Control (22105)

Fenco Shawinigan Engineering Ltd., (1991). *Technical/Economic Study of the Feasibility of Supplying and Utilizing Lingan/Phalen Mine Methane at Lingan Generating Station, Vols. I and II with appendices and set of technical drawings in blueprint format.* Prepared for a consortium including Environment Canada and headed by the Committee on Atlantic Coal.

Kingsley, A.E., (1990). *Proceedings: Evaluation of Integrated Coal Gasification Combined Cycle for Canadian Utility Applications.* Proceedings of workshop co-sponsored by Environment Canada held in Montreal, March 29-30, 1991.

Ontario Hydro, (1990). *Draft Addendum CEA Project Rep. 717G 620.* Prepared for the CEA and Environment Canada.

Ontario Hydro, (1990). *Activation and Recycling of Wastes from In-Furnace Slurry Injection Process.* Draft CEA Project Rept. 802 G 661 prepared for the CEA and Environment Canada.

Ortech International, (1991). *Performance Evaluation of Low Temperature, Low Pressure Drop SCR Technology in a Coal-Fired Boiler Plant.*

Scoulding, D., (1991). *Assessment of European Experience with Selective Catalytic Reduction for Control of NO_x from Fossil Fuelled Boilers, Vols. I and II (Appendices).*

Sypher:Mueller International Inc., (1991). *Development of a Research, Development and Demonstration Program for the Control of Greenhouse Gases from Coal Use.*

Development of Sampling and Analytical Methods for Coal in a Particulate Matrix (22108)

B.C. Research, (1991). *Detection of Coal in Dust Fall Samples, Phase II.* Prepared for a consortium including Environment Canada.

B.C. Research, (1991), *Field-Test of a TEOM Ambient Particulate Monitor.*

Hydrologic Design Methodology for Small-Scale Hydro (41101)

Rousselle, J., C. Marche, S. Birikundavyi, and J. Correa, (1991). *Analyse des fréquences de crues au Québec - Phase I.*

Design Information and Measurement Technology for Solar Energy (42102)

Morris, R.J. and W.R. Skinner, (1990). *Requirements for a Solar Energy Resource Atlas for Canada.* Presented at the 16th Annual Conference on the Solar Energy Society of Canada Inc., Halifax, NS., June 18-20, 1990.

Methane Production from Industrial Wastewaters (45403)

Liver, S., (1990). *The Fate and Effect of Resin Acids in Biological Assays.* M. Eng. Thesis, Department of Civil Engineering, McMaster University, Hamilton.

Schnell, A., J. Dorica, C. Ho, M. Ashikawa, G. Munnoch and E.R. Hall, (1990). *Anaerobic and Aerobic Pilot-Scale Effluent Detoxification Studies at an Integrated Newsprint Mill.* Pulp and Paper Canada, 91(9): T347-352 (Sept. 1990.)

Atmospheric Aerodynamics (46101)

Padro, J. and J.L. Walmsley, (1991). *Spatial Variations of Aerodynamic Resistance Over a Hill.* Air Pollution Modelling and Its Application, pp. 8 (in press).

Walmsley, J.L., (1991). *Climatic Conditions, Section 5.1.2. of Wind-Diesel Guidebook: Sitting, Technology and Implementation.* Internat. Energy Agency, Brussels. (in press).

Walmsley, J.L., (1991). *Wind Resource Assessment, Chapter 4 of Wind-Diesel Guidebook: Sitting, Technology and Implementation.* Internat. Energy Agency, Brussels. (in press).

Walmsley, J.L., D. Woolrdige and J.R. Salmon, (1990). *MS-Micro/3 User's Guide.* Report ARD-90-008.

Carbon Dioxide Advisor (48103)

Environment Canada, (1990). *CO_2 Climate Report.*
Hengeveld, H.G., (1990). *Global Climate Change: Implications for Air Temperature and Water Supply in Canada.* Transactions of the American Fisheries Society, Vol. 119: p. 176-182.

Thomson, J., (1991). *Mechanisms for Reducing Carbon Dioxide Emissions in Canada: A Look at the Transportation, Commercial, Residential and Industrial Sectors.* (Unpublished Report).

Departmental Energy R&D Program Coordination (48108)

Environment Canada, (1991). *Environment Canada Energy Research & Development Program: 1989-90 Annual Report.*

National Groundwater and Soil Remediation Program (48110)

Brewer, J., (1991). *Literature Review and Research Scoping Study on the Treatment of Volatile Organic Carbon Compounds in the Off-Gas from Contaminated Groundwater and Soil Remedial Technologies.* Unpublished report, No. 90-90-03, 80 p.

CH2M Hill Engineering Ltd., (1990). *Literature Review and Scoping Study for the Enhancement of the Volatilization of Organic Contaminants in the Unsaturated Zone.* Unpublished report No. 90-90-04, 53 pp.

Intera Kenting, (1991). *Current and Innovative Excavate and Treat Technologies for the Remediation of Contaminated Soils.*

Major, D., (1990). *In-Situ Bioremediation: Considerations, Limitations, Potential and Future Directions.*

University of Waterloo, (1990). *Site Selection for Demonstration and Evaluation of Technologies for Remediation of Gasoline Spills.*

International Energy Agency Implementing Agreement - Energy Technology Systems Analysis Project (ETSAP) (48111)

Berger. C., R. Loulou, J. Soucy, and J.P. Waaub, (1991). *CO_2 Control in Quebec and Ontario.* Presented at the ETSAP/IIASA Meeting, Laxenburg, Austria, May 1991.

Brookhaven National Laboratory, (1990). *Estimating National Costs of Controlling Emissions from the Energy System; Final Report of Annex III of the Energy Technology Systems Analysis Program.*

Netherlands Energy Research Foundation, (1990-91). *The International Energy Agency ETSAP Newsletter.* Published under Annex IV of the Implementation Agreement for a Programme of Energy Technology Systems Analysis.

Demonstration of Liquid Fuel Production from Sewage Sludge (51202)

Caldwell, R. and H.W. Campbell, (in press). *Leachability of Solid Residues from the Oil from Sludge Process.*

Campbell, H.W. and D.A. Martinoli, (1990). *A Status Report on Environment Canada's Oil from Sludge Technology.* Presented at the WPCF Specialty Conference, December, 1990 at the NRC Workshop, Ottawa, Nov. 1990; ASHRAE Meeting, Ottawa, Feb., 1991 and CANMET Conference Energy and the Environment, Montreal/Toronto, March., 1991.

CANMET, (1990). *Characterization of Sludge Derived Oil and Evaluation of Utilization Options.* Confidential Report.

Pollution Abatement Technologies: Oil Sands/Heavy Oil Upgrading and Natural Gas Processing Wastes (57101)

Croft, B.R., and R.P. Scroggins, (1990). *Gas Plant Sludge Characterization Method.* Presented at the First International Symposium on Oil and Gas Exploration and Production Waste Management Practices, Sept. 1990.

Novak, N., (1990). *Optimization of Organic Contaminant and Toxicity Testing Analytical Procedures for Estimating the Characteristic and Environmental Significance of Natural Gas Processing Plant Waste Sludges.* Prepared for Environment Canada and Canadian Petroleum Association.

Piteau Engineering Ltd. and Integrated Environments Ltd., (1990). *Effectiveness of Subsurface Treatment Technology at Alberta Sour Gas Plants, Phase 1: The Assessment of the Subsurface Contamination and Remediation at Alberta Sour Gas Plants.* Prepared for Environment Canada and Canadian Petroleum Association.

Environmental Implications of Synfuel Processes (57114)

Dearborn Environmental, (in press). Results of the *Thermal Destruction of the Samples from Highland Creek Sludge.*

Hydrogeological Aspects of Heavy Oil/Tarsands Development (57201)

Alberta Research Council, (1991). Report prepared for Environment Canada.

Treatment of Aqueous Effluents from In-Situ Bitumen/Heavy Oil Recovery Operations (57202)

(1991). *Lindberg Area Produced, Water Treatment Study -Phase Two - Part One.* Prepared for Alberta Oil Sands Technology and Research Authority, Environment Canada, Amoco Canada Petroleum

Company Ltd., Dome Petroleum Ltd., Murphy Oil Company Ltd., PanCanadian Petroleum Ltd., Westmin Resources Ltd.

Dearborn Environmental Consulting Group, (1990). *Development of an Automated High-Rate Filter for Treatment of Heavy Oil Recovery Produced Water.*

Simms, K., S. Kok and A. Zaidi, (1990). *Alternative Processes for the Removal of Oil from Oilfield Brines.* Proceedings of the First International Symposium on Oil and Gas Exploration and Production Waste Management Practices, New Orleans, L.A., Sept. 10-13, 1990.

Vachon, D., A. Zaidi and S. Kok, (1991). *A Data Base on the Characteristics of Produced Water from In-Situ Heavy Oil Recovery in Western Canada.* Presented at the CIM/AOSTRA 1991 Technical Conference, Banff, Apr., 1991

Vachon, D., S.A. Zaidi, S. Kok and J. Cunningham, (1990). *Characterization of Produced Water from Selected In-Situ Heavy Oil Recovery Operations in Alberta and Saskatchewan.* Unpublished report No. WTC-PC-1-1990.

Zaidi, A., S. Kok, K. Simms and J.W. Schmidt, (1991). *Oil and Suspended Solids Removal from Produced Water Using Ultrafiltration and Microfiltration.* Presented at the UNITAR/UNDP Fifth International Conference on Heavy Oil and Tar Sands, Caracas, Venezuela, Feb. 1991.

Zaidi, A. and S. Kok, (1990). *Recent Advances in the Treatment of Produced Water from In-Situ Heavy Oil Recovery.* Presented at the Second Canada-China Heavy Oil Technology Symposium, Beijing, China, Oct. 29, 1990.

Treatment and Disposal Practices for Sludges from Heavy Oil Recovery Operations (57203)

Danielson, R.M, E. Peake, N. Okazawa and W.J. Cerroici, (1990). *Disposal of Oilfield Wastes by Land Treatment in Alberta: Summary Report on Feasibility, Environmental Risk Assessments and Future Land Use.* Prepared for Environment Canada and Canadian Petroleum Association.

David Bromley Engineering Ltd., (1991). *Physical and Chemical Characteristics of Oilfield Production Facility Waste Sludges and Solids.* Prepared for Environment Canada and Canadian Petroleum Association.

David Bromley Engineering Ltd., (1991). *Physical and Chemical Characteristics of Natural Gas Processing Plant Waste Sludges and Solids.* Prepared for Environment Canada and Canadian Petroleum Association.

Monenco Consultants Ltd., (1990). *Evaluation of New Technologies for Cleanup of Produced Oily Solids from Heavy Oil Operations.*

Aquatic Assessment Protocols for Oil Sands Operations (57205)

Booty, W.G., I. Wong, D. Kay, and D.C.L. Lam, (1991). *Athabasca River Toxic Chemical Model: Preliminary Results.* NWRI Contribution #91-XX.

Booty, W.G., I. Wong, D. Kay and D.C.L. Lam, (1991). *Athabasca River Toxic Chemical Model: Hydrological Submodel.* NWRI Contribution #91-150, 11 pp.

Bourbonniere, R.A. (Ed.), (1991). *Athabasca River Project 1990/91 Progress Report.* NWRI Contribution #91-XX.

Brownlee, B.G. (Ed.), (1990). *Athabasca River Project 1989/90 -Progress Report.* NWRI Contribution No. 90-76.

Dutka, B.J., K.K. Kwan, S.S. Rao, A. Jurkovic, R. McInnis, G.A. MacInnis, B. Brownlee and D. Liu, (1990). *Ecotoxicological Study of Waters, Sediment and Suspended Sediments in the Athabasca, Peace and Slave Rivers.* NWRI Contribution No. 90-88a.

Fundamental Characteristics of Tailings Pond Sludge (57206)

(1991). *Sludge Fundamentals Project Year Two Report - Operator's Report.* Prepared for the Sludge Fundamentals Consortium made up of AOSTRA/Government/Industry.

(1991). *Sludge Fundamentals Project Year Two Report - Summary & Researcher Reports.* Prepared for the Sludge Fundamentals Consortium made up of AOSTRA/Government/Industry.

Wave Turbulence Interaction (62123)

Drennan, W.M., J. Fenton and M.A. Donelan, (1990). *Numerical Simulation of Nonlinear Wave Groups in Ocean Wave Mechanics, Computational Fluid Dynamics and Mathematical Modelling.* (Ed. Rahman, M.), Continuum Mechanics. pp. 139-146.

Drennan, W.M. and M.A. Donelan, (1991). *Evolving Velocity Fields Under Coalescing Wave Groups.* NWRI Contribution 91-102.

Statistics of Shoaling Waves for Engineering Applications (62124)

Anctil, F., J.C. Doering and M.A. Donelan, (in press). *A Theoretically Consistent Method for Computing the Velocity Field Beneath Wave Groups.* Presented at NRC Workshop on Wave Groups, Ottawa.

Doering, J.C., and M.A. Donelan, (1990). *The Shoaling Waves Experiments.* NWRI Contribution.

Doering, J.C. and M.A. Donelan, (in press). *The Evolution of the Joint Distribution of Wave Height and Period During Shoaling.* Reports submitted to journal.

Donelan, M, F. Anctil and J. Doering, (1991). *A Simple Method for Calculating the Velocity Field Beneath Irregular Waves.* NWRI Contribution 91-111.

Drennan, W.M., K.K. Kahma and M.A. Donelan, (1991). *The Velocity Field Beneath Wind-Waves.* NWRI Contribution No. 91-118.

Hindcasts and Satellite-Sensed Winds (62135)

MacLaren Plansearch Ltd. and Oceanweather Inc., (1991). *Wind/Wave Hindcast Extremes for the East Coast of Canada: Volume I.*

MacLaren Plansearch Ltd. and Oceanweather Inc., (1991). *Wind/Wave Hindcast Extremes for the East Coast of Canada: Volume II - Georges Bank Tropical Storm Hindcast.*

Climate Change and Arctic Offshore Energy Development (62143)

Environment Canada, (1990). *Impacts of Climatic Change on the Beaufort Sea-Ice Regime.* Internal report, pp. 1-120.

Sea Ice Distribution (62322)

Agnew, T. (1991). *Simultaneous Winter Sea Ice and Atmospheric Circulation Anomaly Patterns.* J. of Atmosphere-Ocean. (Submitted).

Marine Icing (62323)

Brown, R.D., P.T. Mitten, L. Makkonen, E.P. Lozowski, W.P. Zakrzewski and M. Waszkiewicz, (1990). *Modelling and Measurement of Spray Ice Accretion on Offshore Structures.* Presentation made at 5th International Workshop on Atmospheric Icing of Structures, Tokyo, Japan, Oct. 29-31, 1990, Paper B2-5, 6 pp.

Canadian Climate Centre, (1991). *Marine Icing Newsletter, Vol. 5, Jan. 1991.*

Compusult, (1990). *Spray Measurement Field Program, Phase 1 - May 9 to 15, 1990.* Prepared for Environment Canada, 17 pp.

Lozowski, E.P. and W.P. Zakrzewski, (1990). *Icing Wind Tunnel Measurements.* 64 pp.

Makkonen, L., R.D. Brown and P.T. Mitten, (1990). *Comments on "Prediction of Vessel Icing for Near-Freezing Sea Temperatures".* Weather and Forecasting, 6, 4, pp. 565-567.

Ice Digitation Technology Development (62338)

Piwowar, J.M., E.F. LeDrew, R. Chagnon, and D. Mudry, (1990). Sicar: *A Program for Semi-Automated Digitizing of Composite Ice Charts.* Presented at the 2nd WMO Operational Ice Remote Sensing Workshop, September, 1990.

Satellite Radar Studies (67116)

Park, A., (1991). *Flight Saving Based on ERS-1 Orbit Predictions for 1993.* Ice Centre internal report.

Wills, P., (1990). *Application of RADARSAT SAR Data to the Operational Ice Program.* Ice Centre internal report.

Canadian Atlantic Storms Program II (67150)

Stewart, R.E., (1991). *Canadian Atlantic Storms Program: Progress and Plans of the Meteorological Component.* Bull. Amer. Meteor. Soc., 72, pp. 364-371.

Ocean Wave Modelling (67155)

Khandekar, M.L. and R. Lalbeharry, (1990). *A Forecaster's Guide to the Canadian Ocean Wave Model.* Atmospheric Research Directorate, internal report ARD-90-007, 41 pp.

Experiment on Rapidly Intensifying Cyclones over the Atlantic (ERICA) (67156)

Isaac, G.A., (1991). *Microphysical Characteristics of Canadian Atlantic Storms.* Atmos. Res., 26, pp. 339-360.

Lin, C.A. and R.E. Stewart, (1991). *Diabatically Forced Mesoscale Circulations in the Atmosphere.* Advances in Geoph., 33, pp. 267-305.

Raga, G.B., R.E. Stewart and N.R. Donaldson, (1991). *Microphysical Characteristics Through the Melting Region of a Mid-Latitude Winter Storm.* J. Atmos., 48, pp. 843-855.

Raga, G.B., J.W. Strapp, and R.E. Stewart, (1991). *Mesoscale Structure of Precipitation Bands in a North Atlantic Winter Storm.* Presented at *IUGG Congress*, Vienna.

Stewart, R.E., (1991). *On the Temperatures near and the Motions of Low-Pressure Centres in Winter Storms.* Atmos. Res., 26, pp. 33-54.

Stewart, R.E., R.W. Crawford and N.R. Donaldson, (1990). *Precipitation Characteristics within Several Canadian East Coast Winter Storms.* Atmos. Res., 25, pp. 293-316.

Stewart, R.E., R.W. Crawford, N.R. Donaldson, T.B. Low and B.E. Sheppard, (1990). *Precipitation and Environmental Conditions During Accretion in Canadian East Coast Winter Storms.* J. Appl. Meteor., 29, pp. 525-538.

Stewart, R.E. and C.A. Lin, (1991). *Strongly Temperature Dependent Microphysical Processes and the Atmosphere.* Geoph. Res. Let. (Submitted)

Stewart, R.E., C.A. Lin and S.R. Macpherson, (1990). *The Structure of a Winter Storm Producing Heavy Precipitation over Nova Scotia.* Mon. Wea. Rev., 118, pp. 411-426.

Taylor, P.A., J.R. Salmon, and R.E. Stewart, (1991). *Mesoscale Observations of Surface Fronts and Low Centres in Canadian East Coast Winter Storms.* Atmos.-Ocean (Submitted).

Taylor, P.A., J.R. Salmon and R.E. Stewart, (1991). *Aspects of the Surface Structure of Canadian East Coast Winter Storms.* Atmos.-Ocean (Submitted).

Operational Ice Modelling (67158)

Arctic Sciences Ltd. and ASA Consulting Ltd., (1991). *Sea Ice Model Verification Project: Labrador Sea/East Newfoundland Waters.*

FG Bercha and Associates Ltd., (1991). *Sea Ice Forecast Model Verification for the Beaufort Sea.*

Norland Science and Engineering Ltd., (1990). *Sea Ice Model Verification Study Background Documentation.*

Sea Ice Tracking Algorithm (67167)

Noetix Research Inc., (1991). *Ice Tracking Software Functional Specifications Document, Version 2.1.*

Integrated Hydrocarbon Monitoring (67237)

Barringer Resources, (1991). *Monitoring of Plankton Productivity, Migration of Juvenile Salmon and Oil Pollution Using a Newly Developed Airborne Fluorescent Sensor - Phase I).*

Condensate Effects on Commercial Species (67238)

(1991). *Method Development for the Analysis of Tainting Compounds.*

(1991). *Tainting Potential of an Oil Dispersant: Effects of Sea Scallops.*

Organic Pollutants from Flare Stacks (67239)

Alberta Research Council, (1991). *A Review of Flaring in the Sour Gas Industry with Particular Reference to the Emission of Pollutants.*

Treatment of Wastewater from Offshore Oil Production (67245)

Simms K., S. Kok, and A. Zaidi, (1990). *Alternative Processes for the Removal of Oil from Oilfield Brines.* Presented at the First International Symposium on Oil and Gas Exploration and Production Waste Management Practices, New Orleans, Louisiana, Sept 10-14, 1990.

Smyth I.C., and M.T. Thew, (1991). *Testing of a Vortoil Deoiling Hydrocyclone with Terra Nova Crude.*

Zaidi A., S. Kok, K. Simms, and J.W. Schmidt, (1991). *Oil and Suspended Solids Removal from Produced Water Using Ultrafiltration and Microfiltration.* Presented at the UNITAR/UNDP Fifth International Conference on Heavy Oil and Tar Sands, Caracas, Venezuela, Feb. 1991.

Pollution from the Offshore Oil Industry: Putting it into Perspective (67267)

Wilkinson, B., (1991). *An Interpretative Study of the Expected Inputs and Effects of Pollutants Released into the Marine Environment by Oil Rigs and Platforms, Ships and Fishing Vessels.* 184 pp.